EVALUATION OF A CYLINDRICAL WEDGE-WIRE SCREEN SYSTEM AT BEAL LAKE, ARIZONA, 2005

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EXECUTIVE SUMMARY

Beal Lake is a historical backwater on the Lower Colorado River that is being developed as a protected habitat for native lower Colorado River fishes. As a part of Reclamation's continuing activities for Endangered Species Act compliance, major improvements were made to this backwater to make it suitable for native fishes. Among these improvements was the installation of a permeable rock structure to prevent passage of nonnative fish into Beal Lake from the adjacent Topock Marsh. However, while the rock structure effectively blocked passage of nonnative fish, it was found to be inadequate in passing enough water to balance evaporative losses that occur in Beal Lake during summer months. The inlet water for Beal Lake comes from Topock Marsh. As part of Reclamation's continued commitment to provide protected habitats for native lower Colorado River fishes under the Lower Colorado River Multi-Species Conservation Program, the rock structure was modified with the installation of an experimental cylindrical wedge-wire screen system. This prototype screen system was intended to compensate for evaporation loss in Beal Lake as well as exclude all life stages of nonnative fishes. The objectives of this study were to evaluate the hydraulic performance of the screen system, determine if the screen material used in construction is an effective anti-biofouling agent, and to develop a cleaning and maintenance schedule.

To assess the hydraulic performance of the screen system, a two-stage evaluation plan was developed. The first component of the evaluation was to establish a long-term recording station to regularly monitor water levels on either side of the rock structure, and determine whether differences in water levels were occurring. The second component was to directly measure the volume of water flowing through the screen systems to compare with estimates of evaporation and evapotranspiration from Beal Lake. To assess the effectiveness of the screen material in preventing biological growth, samples of various screen material were deployed throughout the summer, and later retrieved to assess the amount and type of material found on them. An evaluation of the air backwash system was conducted to test its effectiveness for removing debris from the screens. Results of this evaluation were combined with the screen test to develop a long-term maintenance schedule.

Based on the results of the two-stage evaluation on hydraulic performance, the screen system does provide adequate water flow to compensate for evaporative losses from Beal Lake. Mean daily water levels on either side of the rock structure remained within 0.15 ft of equilibrium during July and August when evapotranspiration from Beal Lake was estimated to be high. This minimal difference in water levels was an improvement compared an observed difference of nearly 2 ft prior to the installation of the screen system. The flow measurements through the screen system indicated that

the pipe system is capable of delivering approximately 29.7 acre ft/day; a value more than 4 times greater than the highest estimated evapotranspiration rate for Beal Lake (7 acre ft/day) in the summer.

The comparison of the screen samples suggests that the anti-biofouling screen material may not be necessary. The deposits found on all the samples were similar, and largely comprised of decaying organic matter and mineral particulates (*e.g.* silt and clay). However, our evaluation was limited by the number of samples tested, and further evaluation is necessary before more conclusive results can be obtained. It is also recommended that testing be conducted in other locations where this technology may be used such as the main river channel.

The air backwash system designed to clean each screen was found to be inadequate at an air pressure of 80 psi. While higher air pressure may more effective in cleaning the screens, we found that manually brushing the screen was an efficient and effective cleaning method. Physical brushing was found to be particular efficient at cleaning the lower portions of the screens, and would allow maintenance personnel to check the screen integrity. We recommend that the screens be cleaned by brushing on a monthly basis in the summer, and less regularly during the remainder of the year.

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1.0 ISSUE STATEMENT

Evaluate prototype cylindrical wedge-wire screen system to determine hydraulic and anti-biofouling performance, and to develop a long-term maintenance schedule.

2.0 INTRODUCTION AND OBJECTIVES

Several species of native Colorado River fishes, including the razorback sucker (*Xyrauchen texanus*) and the bonytail chub (*Gila elegans*), have been listed as endangered species under the terms of the Endangered Species Act (ESA; Minckley 1983; Mueller 2005). Human modifications to the lower Colorado River system have fundamentally changed the hydraulic characteristics of the river and the conditions under which these species evolved (Minckley and Deacon 1968; Fradkin 1981). These altered river conditions favored the population growth of introduced nonnative fishes that have existed in the system since the late nineteenth century (Dill 1944). Early declines of native fish were attributed to habitat alternations caused by dam construction; however in the past few decades it has become apparent that competition and predation from nonnative species is likely the most consequential factor preventing the continued existence and potential recovery of endangered native fishes (Meffe 1985; Minckley 1991; Marsh and Pacey 2005). As it is highly unlikely that the hydraulic conditions of the Colorado River will ever resemble the conditions found historically, and it would be nearly impossible to extirpate nonnative fishes completely from the system, one recovery strategy currently being investigated is creating isolated, predator-free habitats for native fishes (Mueller 2005). Creation of isolated, predator-free habitats involves renovating and protecting backwaters along the Colorado River by improving habitat conditions (*i.e.,* dredging), chemically removing all nonnative fishes, and restocking these areas with native fauna. However, the success of these projects depends primarily on the continued exclusion of nonnative fishes.

The U.S. Bureau of Reclamation (Reclamation) is required to create protected backwaters for native species along the lower Colorado River to comply with their responsibilities under the terms of the ESA. Under this requirement, protected backwaters should provide recovery habitat for endangered native fishes and inhibit the invasion and subsequent recolonization of nonnative fauna. Beal Lake, located on Havasu National Wildlife Refuge near Needles, CA was identified as a candidate backwater to develop as a protected habitat for native fishes. Improvements to Beal Lake included substantial dredging and the installation of a permeable rock filtration system (hereafter referred to as "the rock structure"). The system is located on the inlet canal between Topock Marsh and Beal Lake. This inlet canal provides the only surface connection between Beal Lake and the lower Colorado

River. The rock structure was designed to exclude all life stages of nonnative fish while allowing an adequate volume of water to enter Beal Lake to balance evaporative losses (Love and Vizcarra 2000).

Shortly after the installation of the rock structure, a head difference was observed between the Topock Marsh and Beal Lake. This difference became pronounced (nearly 2 ft) in subsequent months (personal communications Gregg Garnett, Bureau of Reclamation, Boulder City, NV). It was determined that the permeable filter within the rock structure was at least partially clogged with silt and other particulates and was not passing an adequate volume of water to balance evaporative losses in Beal Lake. Reclamation assumed that clogging was the result of suspended solids in the water column, improper construction of the rock filter, or some combination of both these factors. The inadequate performance of the rock structure provided the impetus for a re-evaluation and investigation of alternate technologies and/or modifications that could improve water flow into Beal Lake. Based on a thorough review of the literature, Reclamation chose to experiment with technologies other than permeable rock barriers and add a total of four 18 in diameter pipes through the rock structure to provide additional flow into Beal Lake. To inhibit movement of fish through the pipes, high-volume, cylindrical wedge-wire screens were installed at either end of installed pipes.

The prototype cylindrical wedge-wire screen system was installed in spring 2005. The purpose of this evaluation was to monitor the performance of the screen system, with the specific objectives of:

Objective 1. Estimate the volume of flow passing through the screen system, and evaluate whether enough flow is being delivered to adequately balance evaporation losses in Beal Lake;

Objective 2. Determine if the anti-fouling alloy is effective in inhibiting algal and other biological growth; and

Objective 3. Estimate how often is it necessary to operate the screen backwash system, and propose a screen system operation and maintenance schedule.

3.0 STUDY AREA

Beal Lake is a 225-acre backwater located adjacent to Topock Marsh on the Havasu National Wildlife Refuge in Mohave Valley, AZ (near Needles, CA, Figure 1). The rock structure and modified screen system are located on the northern end of the inlet canal, which supplies water from Topock Marsh to Beal Lake (Figure 2). Beal Lake and Topock Marsh are both eutrophic water bodies, and contain a high amount of suspended solids in the water column (King *et al*. 1993). Water from the Colorado River enters Topock Marsh through control gates at the South Dike outlet structure (USGS gage no. 09423550, Topock Marsh Inlet near Needles, CA). Water elevations in Topock Marsh and Beal Lake vary through the year, but are generally highest in May-June and lowest in December-January (surface elevation 456.7 ft in summer to 454.7 ft in winter). Local climate in the area is seasonally variable, with wintertime air temperatures dropping below 30^{o}F and summertime temperatures exceeding 120^{o}F. Evapotranspiration from marsh vegetation on the refuge is estimated to be highest in June (11.14 in/month), and lowest in November (0.60 in/month) and December (0.64 in/month; BOR 2003).

The screen system is comprised of four 18 inch diameter PVC pipes, of which, three are equipped with cylindrical wedge-wire screens on either end (Figure 3). The remaining pipe is capped and may be fitted with screens in the future if evaluations show that additional flow is necessary. An in-line valve was installed in the middle of each pipe that can be accessed from the rock structure, to allow the pipes to be closed when necessary (*e.g*., repair or replacement of screens). The screens were constructed of Z-Alloy, an anti-biofouling nickel-copper alloy. Each screen is equipped with an internal diffuser and 3-inch air backwash system. The diameter of each screen cylinder is 33.25 inches, and each cylinder is 36.56 inches long (Appendix A). The screen slot size is 0.6 mm (0.024 inches), which was chosen to exclude the smallest egg and larval stages of nonnative fishes (*i.e.,* threadfin shad *Dorosoma petenense* 0.7 – 0.9 mm; Hubbs and Bryan 1974). Each screen has an expected capacity of 1,500 gpm.

Two water control gates are located on either side of the rock structure, and can be closed to hydraulically isolate the rock structure. A stationary 9,000 gpm irrigation pump is located on the Topock Marsh side of the rock structure, and is used to irrigate surrounding fields. By using the water control gates and irrigation pump, various flow conditions can be simulated across the screen system.

4.0 MATERIALS AND METHODS

The hydraulic performance of the cylindrical wedge-wire screen system was evaluated on three separate occasions:

July 7 – 16, 2005 (High water level)

October 4 – 6, 2005 (Medium water level)

December 6– 8, 2005 (Low water level)

These sampling periods were designated to coincide with periods of high, medium, and low water levels in Beal Lake.

4.1 Objective 1. – Evaluation of screen system hydraulic performance

To assess the hydraulic performance of the screen system, a two-stage evaluation plan was developed. The first component of the evaluation was to establish a long-term recording station to regularly monitor water levels on either side of the rock structure. This monitoring station was used to determine whether differences in water levels were occurring during any time of the year. The second component was to directly measure volume of water flow through the screen systems to compare with estimates of evaporation and evapotranspiration from Beal Lake.

4.1.1 Installation of Long Term Water Level Monitoring System (SIT60)

The long-term water level monitoring system (Global Water SIT60) was installed on 10 July, 2005 and data collection was initiated at 16:40 hrs. The satellite uplink station and attached solar panel were mounted on the western side of the rock structure (Figure 4). Two water level sensors were suspended in the water column on either side of the rock structure; one to monitor water elevation in the Topock Marsh embayment; and one to monitor water elevation in the Beal Lake embayment. A water temperature sensor was installed in conjunction with the water level monitor in Beal Lake. All measurements were recorded hourly, and remotely monitored along with system status and battery life by satellite uplink. Routine calibration of the water elevation monitors was conducted to ensure data quality.

Mean daily water level measurements on each side of the rock structure were calculated from hourly readings over a 24-hr period. Differences between the mean daily water level measurements on either side of the rock structure were compared throughout the summer and fall to determine whether a difference in water levels occurred.

4.1.2 Evaluating Water Flow through the Screen System

To assess the volume of water flowing through the screen system, an electromagnetic flow meter (Marsh-McBirney FLO-TOTE II) was installed into one of the screened pipes (Figure 5). All valves controlling flow through the pipes in the rock structure were closed, as were all the valves controlling flow from Topock Marsh. With the Topock Marsh embayment isolated, the stationary irrigation pump was used to lower the Topock Marsh embayment and create a water level differential across the rock structure. Once the head differential reached approximately 2 ft, the inline valve on the pipe with the installed flow meter was opened. Water levels on either side of the rock structure were monitored simultaneously using data logging water level sensors that were set to record water depth on both sides of the rock structure every minute. Data were recorded until water levels on either side of the rock structure reached equilibrium.

Flow measurements were recorded during each sampling period to evaluate system performance at high, medium and low water levels. Regression analysis was employed to predict water flow through the screen system as a function of head differential on either side of the rock structure. Measurements of water flow through the pipe were compared with the highest monthly estimates of evapotranspiration for 225 acres of marsh habitat (BOR 2003). Estimates of evapotranspiration were used rather than estimates of open water evaporation for Beal Lake, because estimates of evapotranspiration were generally higher than estimates of open water evaporation during the summer months (Figure 6), and therefore allowed for a comparison based on the highest anticipated rate of water loss.

4.2 Objective 2. – Evaluation of anti-fouling alloy screen material

To assess the effectiveness of the Z-Alloy in preventing biological growth, screen samples of the Z-alloy and non-Z-Alloy (304 stainless steel) material were installed side by side near the existing screened pipes (Figure 7). Samples were suspended in the water, and were allowed to remain in the water undisturbed throughout the summer until they were retrieved. Immediately following their retrieval, the screen samples were sealed in plastic bags, placed on ice, and shipped directly to the Normandeau Associates Biological Lab for analysis. At the Lab, a qualitative comparison of each sample was conducted. All inorganic and organic materials found on each screen sample were identified, and evaluated to determine their level of adhesion.

4.3 Objective 3. – Evaluation of screen system operation and maintenance

An evaluation of the air backwash system was conducted to test its effectiveness for removing debris from the screens. A truck mounted air compressor was attached to the internal diffuser of each pipe and compressed air was forced through the backwash system at a pressure of up to 80 psi (Figure 8). Visual observations of the amount of material on the screens were made prior to and following the operation of the air backwash system. Other screen cleaning methodologies were also evaluated. These methodologies included physical brushing of the screens with a nylon brush and adjusting water levels to increase pipe flow.

5.0 RESULTS

5.1 Objective 1. – Evaluation of screen system hydraulic performance

Mean daily water levels on either side of the rock structure remained within 0.15 ft of equilibrium during July and August when evapotranspiration from Beal Lake was estimated to be high (Figure 9; BOR 2003). For the remainder of the year, the difference in water levels remained within 0.1 ft of equilibrium. During time periods when irrigation was occurring, and the pump in the Topock embayment was operated, water levels on both sides of the rock structure decreased approximately 0.3 ft. However, water levels on either side of the rock structure returned to previous levels within an hour after operation of the pump ceased (Appendix B). Water temperatures recorded at the station decreased from a high of 93° F recorded in July to a low of below 50° F in December (Figure 10).

The flow measurements through the screen system indicate that each pipe is capable of delivering approximately 5 cfs or 9.9 acre ft/day of water at a 2 ft head differential; the combined capacity of the 3 pipes currently screened is approximately 29.7 acre ft/day. This combined value is more than 4 times the 7 acre ft/day evapotranspiration rate estimated to occur from Beal Lake during the summer (BOR 2003).

Because flow through the pipe was non-linear, power regression was used to estimate pipe flow as a function of head differential (Figure 11). The best-fit equation yielded an $r^2 = 0.998$, and was calculated as:

$$y = 3.6969x^{0.6167}$$

where,

x = water level differential on either side of the rock structure; and

y = in-pipe flow for a single pipe.

5.2 Objective 2. – Evaluation of anti-fouling alloy screen material

One Z-Alloy and two non-Z-Alloy screen samples were suspended in the water column at a depth of approximately 1 m, and adjacent to one of the screened pipes on the Topock side of the rock structure. The Z-Alloy sample measured 100 mm by 207 mm and consisted of 60 individual ribs measuring 2 mm tall (Figure 7). The non-Z-Alloy samples each measured 180 mm by 151 mm and contained 25 individual ribs measuring 2 mm tall. The samples were suspended in the water on 15 July, and remained in the water undisturbed for a total of 82 days until they were retrieved on 4 October.

Based on side by side comparisons, the Z-Alloy screen sample appeared to be more heavily fouled than the non-Z-Alloy samples. The entire surface of the Z-Alloy sample (both sides) was covered with a microbial mat that filled approximately 90% of the interstitial spaces between the screen ribs. The microbial mat on the screen consisted of a mixture of various bacterial colonies and their extracellular metabolites, decaying organic matter, and mineral particles (*i.e.,* silt and clay). A variety of small invertebrates such as nematodes, rotifers, oligochaetes and ostracods were found to be living within the microbial mat that covered the screen sample. The outer smooth surface of the screen sample contained a large number of diatoms. Animal tubes, inhabited by several species of chironomids were also numerous on the Z-Alloy screen sample and, in some areas, completely covered the panel face. The underside of the sample also had a relatively small colony of the ectoproct bryozoan (*Plumatella casmiana*). The colony appeared to be in a dormant state, but there were numerous statoblasts (*i.e.,* reproductive structures) present.

Approximately 30% of the surface of each non-Z-Alloy sample was covered with a thin layer microbial mat, with the remaining surface area being clear. The outer surfaces of the samples were almost entirely clear of fouling material with a few animal tubes (particularly Chironomids) on the inner side of the screen (the side containing the cross-supports).

None of the organisms were observed to be securely cemented to either the Z-Alloy or non-Z-Alloy screen samples as is often observed with barnacles and some insects. The bryozoans, and animal tubes were lightly attached to the surface of the screen samples although they seemed to be relatively easily removed by light scraping or brushing. The microbial mats were also easily removed by light surface agitation.

5.3 Objective 3. – Evaluation of screen system operation and maintenance

An evaluation of the air backwash system was conducted on 12 July, 2005. A Bureau of Reclamation crew from Yuma, Arizona operated the backwash system. Each screen was backwashed with a maximum of 80 psi; higher air pressure was not tested due to uncertainty regarding the limits of the screen system. As the air backwash system was operated, a large plume of sediment was observed dissipating off the screens (Figure 12). However, physical inspection of the screens while the backwash system was in operation revealed that a majority of the air from the airburst system was escaping through the upper portion of the screen, thereby effectively cleaning only the upper third of the screen. The limited ability of the air backwash system to clean the entire screen was evident when the screens were dewatered following the procedure and sediment was observed to be still covering a majority of the screen surface. Sediment was observed to be especially thick on the lower portions of the screens. As an alternative method of cleaning the screen, a nylon utility brush was used to scrub the external surface of the entire screen surface. This proved to be a relatively quick and effective method for removing surface sediment and other material from the surface of the screens.

5.4 Other Findings

During operation of the air backwash system, a filamentous material was observed to be extruding through the interstitial spaces of the screens. This filamentous material appeared to be impinged on the inside of the screens and was apparently dislodged from the inside of the pipe during the test of the airburst system. Samples of this material were collected and were sent to the Normandeau Biological Lab for identification. Results of this analysis indicated that the filamentous material was a colonial hydrozoa from the genus *Cordylophera*. These hydrozoa were found to be attached to the inside of the PVC pipe, and were evident on a section of pipe removed during the installation of the flow meter (Figure 13). The hydrozoan on the inside of the pipes appeared to be covered with inorganic silt, which may lead to reduced pipe flow. It should be noted that there was no evidence of hyrdrozoan growth on the outer surfaces of any of the screens, on the screen samples deployed as a part of the Objective 3 evaluation, or the outside of the PVC pipes.

It was observed when the water level in the Topock embayment was drawn down to create a head differential between the embayments, there was a noticeable volume of water permeating through the rock structure (Figure 14). This was particularly evident along western side of the structure immediately adjacent to the flow through pipes. While the level of permeation was likely influenced by increased pressure from adjusting water levels on either side of the rock structure, substantial infiltration of flow through rock structure could have a negative effect on the biological exclusion ability of the screen system.

The flow control structure that is located in the canal connecting the rock structure to Beal Lake consists of a single 24-inch box-culvert buried within an earthen dam (Figure 15). During our evaluation of the screen system, we noticed that a considerable amount of water was moving through this structure. While this flow was not measured, based on the size of the structure, we estimated the hydraulic capacity of the screen system is nearly twice that of the box-culvert. Consequently, the rate of water being delivered into Beal Lake may be limited.

6.0 DISCUSSION

Based on the observed hydraulic performance, the prototype screen system clearly provides enough water flow to compensate for evaporative losses from Beal Lake. Throughout the summer and fall, the difference in water levels observed on either side of the rock structure remained less than 0.15 ft. This minimal difference in water levels was a great improvement when compared to the difference of nearly 2 ft observed prior to the installation of the screen system. These results are consistent with the flow measurements taken directly form the pipe, which indicated that the system is capable of delivering approximately 29.7 acre ft/day. This value is more than 4 times greater than the highest estimated evapotranspiration rate for Beal Lake (7 acre ft/day) in the summer (BOR 2003).

Our overall comparison of the system's hydraulic performance with summertime water loss is likely conservative. Estimates of evapotranspiration, rather than open water evaporation, were used to estimate water loss from Beal Lake. These evapotranspiration estimates were typically 1.5 times higher in the summer than estimates of open water evaporation. As Beal Lake is predominately open water rather than marsh habitat, using the higher estimate of evapotranspiration as the standard for water loss ensured that the comparison was robust. Our estimates of water flow through the screen systems also did not account for water flow passing directly through the rock structure. The rock structure was originally designed as a passive filtration system and while early observations determined that the rock filter was partially clogged, some flow still passes through the structure. This was evident when the Topock embayment was drawn down, and water was observed to be permeating the rock structure.

Although our evaluation did not monitor water levels during the month of June when evapotranspiration rates are estimated to be highest, visual observations in June indicated that no discernable difference in water levels occurred on either side of the rock structure (personal communications Gregg Garnett, Bureau of Reclamation, Boulder City, NV). In addition, our initial evaluation of the rock structure began in July, when air temperatures at the study site reached approximately 125^{o} F and relative humidity was low. While estimates of evapotranspiration during this period suggest a slightly lower rate than in June, the observed conditions likely represented the highest levels of evaporative losses from Beal Lake for the year. Consequently, our observations recorded in July are probably similar to conditions estimated to occur in June.

The side by side comparison of the screen samples suggests that the non-Z-Alloy screen material is as effective as the Z-Alloy material for inhibiting biological growth. The deposits found on all the samples were similar, and largely comprised of decaying organic matter and mineral particulates (*e.g.* silt and clay). However, these results should be interpreted cautiously. The limited number of samples significantly reduces the power of our evaluation, and an evaluation using more samples is necessary before more conclusive results can be obtained. In addition, our evaluation did not account for possible differences in water quality, species composition, and habitat that may be encountered during future applications of the screen system. Water clarity in Beal Lake is considerably lower than in the main river channel, and the anti-biofouling properties of the Z-Alloy screens may be more necessary at potential locations along the main river channel than in Beal Lake. Our limited analysis found that most of the material found on the screen samples was inorganic, but this inorganic material provided a substrate for microbes and various invertebrates to live. In habitats with higher water clarity (such as along the main river channel), the potential for algal growth is greater, and using Z-Alloy may be necessary.

The air backwash system was found to be inadequate for cleaning the entire surface of the screens. At an air pressure of 80 psi, only the upper third of the screen was cleaned. While increasing the amount of pressure may more effective at cleaning the screens, we found that using a nylon brush and physically brushing the screen was an efficient cleaning method. Physical brushing was found to be particularly efficient at cleaning the lower portions of the screens, and allowed maintenance personnel the opportunity to visually check the integrity of the screens. However, a limitation of brushing the screens is that it is not an effective at removing sediment from inside the pipes. A solution for this at Beal Lake would be to create a head differential across the rock structure by using the irrigation pump and artificially increasing the velocity of water flowing through the pipes [similar to the conditions created to test pipe flow in Objective 1]. The ability to artificially adjust water levels may not be possible at other locations. However, at sites along the main river channel sediment acclimating in the pipes may not be an issue as water clarity is greater, and daily fluctuations in river flow (and consequently water levels) may naturally elevate water flow through the pipes and keep in-pipe sediment deposits low.

7.0 RECOMMENDATIONS

- *Evaluation of secondary flow structure leading into Beal Lake* — While our analysis indicated that water flow through the screen system is adequate to compensate for evaporative losses during the summer, the box-culvert located on the inlet channel may be limiting water into Beal Lake. It is recommended that this downstream flow control structure be evaluated, and if necessary, modified to increase the hydraulic capacity or removed entirely.

- *Screen maintenance* — Use of the air backwash system was found to inadequately clean the entire surface of the screens. In contrast, physically brushing the screens was found to be an effective cleaning method, and would require a minimal investment in materials and personnel time. We recommend brushing of the screens once a month during May, June, July, and August to ensue optimum system operation when evaporative losses are highest. Bimonthly brushing of the screens is recommended during other months when evaporative losses from Beal Lake are lower. Artificially increasing the amount of water flow through the pipes by augmenting water levels using the irrigation pump is recommended at Beal Lake annually to reduce in-pipe sediment deposits.

- *Continued evaluation of Z-Alloy* — We recommend that further evaluation of the effectiveness of Z-Alloy as an anti-biofouling agent should be conducted in Beal Lake using a large number of screen samples. These evaluations should also be extended into waters closer to the main channel of the Colorado River where water conditions are different than those found in Beal Lake.

- *Over-engineer for hydraulic performance* — It is recommended for future installation using wedge-wire screen technology that the system be over-engineered to achieve optimum hydraulic performance. The screen system was designed to provide flow at a rate approximately 4 times the anticipated maximum volume of evapotranspiration loss from Beal Lake. This over-engineering provides a safeguard for overall system performance, and may reduce the need for routine screen cleaning. This factor may be particularly critical in applications of the screen technology at more remote locations.

- *Evaluation of water flow through the rock structure* — Quantifying the volume of flow passing through the rock structure was not conducted during this evaluation. During testing, we observed water permeating though the rock structure. Information regarding the volume of flow passing through the existing rock structure at Beal Lake may prove to be valuable when designing and installing screen systems at other locations. In addition, the amount of flow permeating through the rock structure should be evaluated to assess the integrity of the rock structure in excluding all life stages of nonnative fishes.

- *Hydrozoan control* — The presence of filamentous colonial hydrozoans attached to the inside of the PVC pipes was not anticipated. While the long term effects of hydrozoan growth on the inside of the pipes is not yet known, this situation should be closely monitored and methodologies for discouraging hydrozoan growth or removing them from inside the pipes should be developed. If the presence of hydrozoan inside the pipes proves to be detrimental to the system's performance, it may be necessary to re-engineer the system to accommodate internal cleaning, or develop possible chemical or mechanical treatment practices.

- *Nonnative fish exclusion* — Continue with planned evaluation of the biological effectiveness of the screen systems at Beal Lake in excluding all life stages of nonnative fishes. This evaluation should be conducted at a location away from the existing screen systems where conditions can be readily controlled and replicated, and the effectiveness of the exclusion performance of the screen systems more reliable evaluated. Furthermore, evaluation of the exclusion effectiveness of the screens in a laboratory setting will eliminate the possibility of introducing nonnative fishes into Beal Lake and will allow the evaluation to include multiple species and life stages of nonnative fishes.

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FIGURES

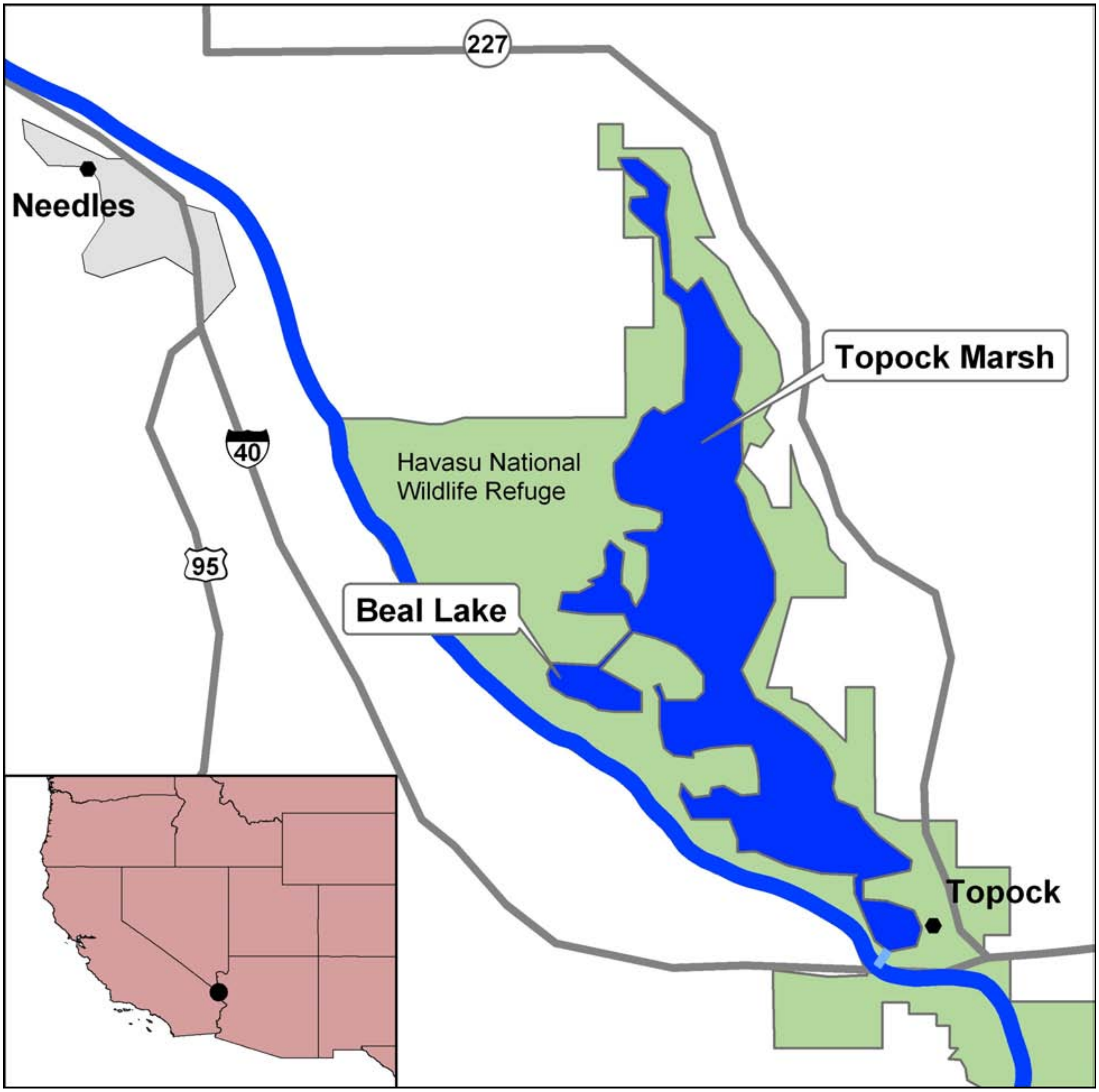


Figure 1. Study area map of Beal Lake in relation to Topock Marsh on the Havasu National Wildlife Refuge, Arizona.

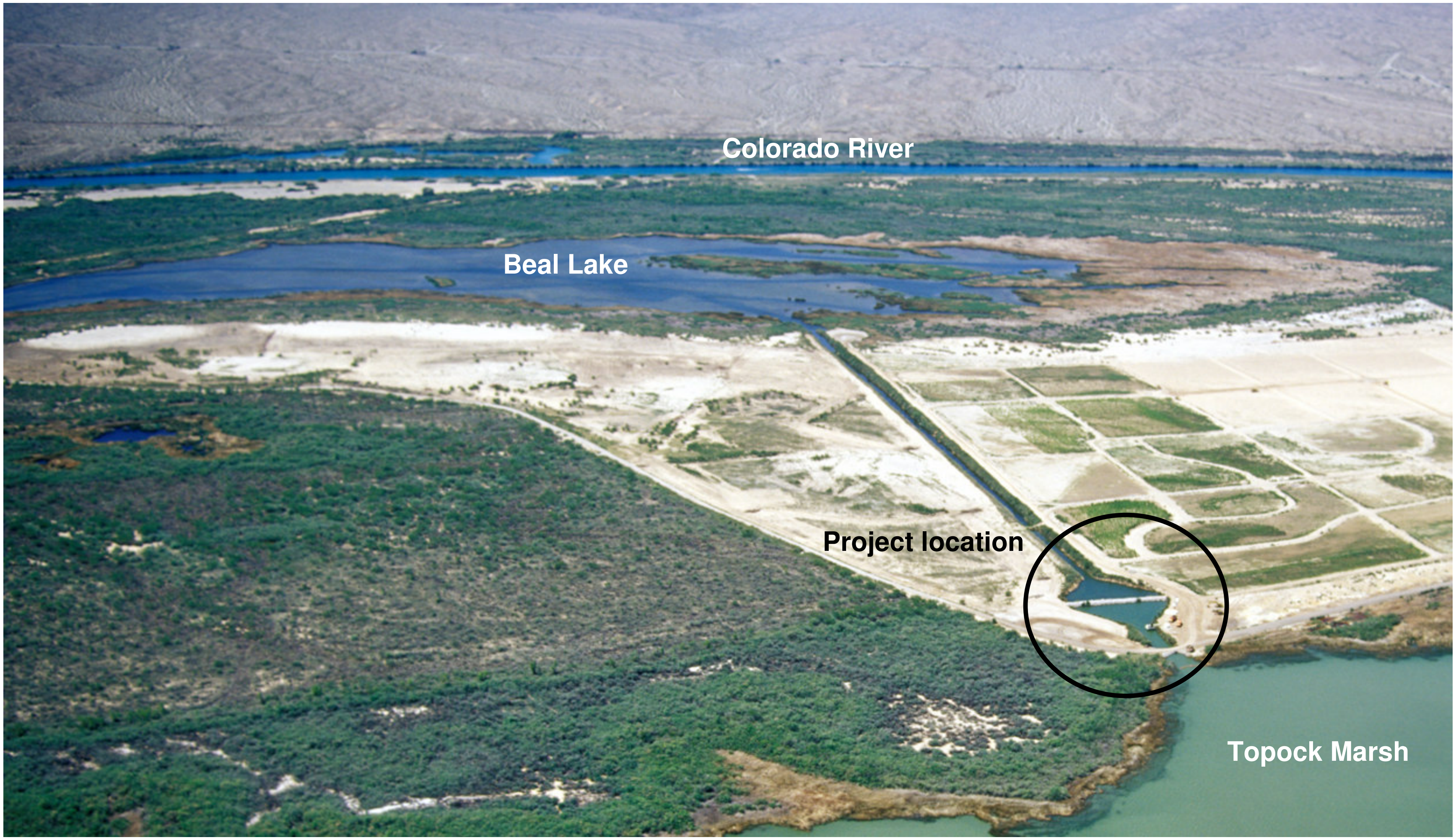


Figure 2. Aerial photo of rock structure located on the inlet canal between Topock Marsh and Beal Lake.

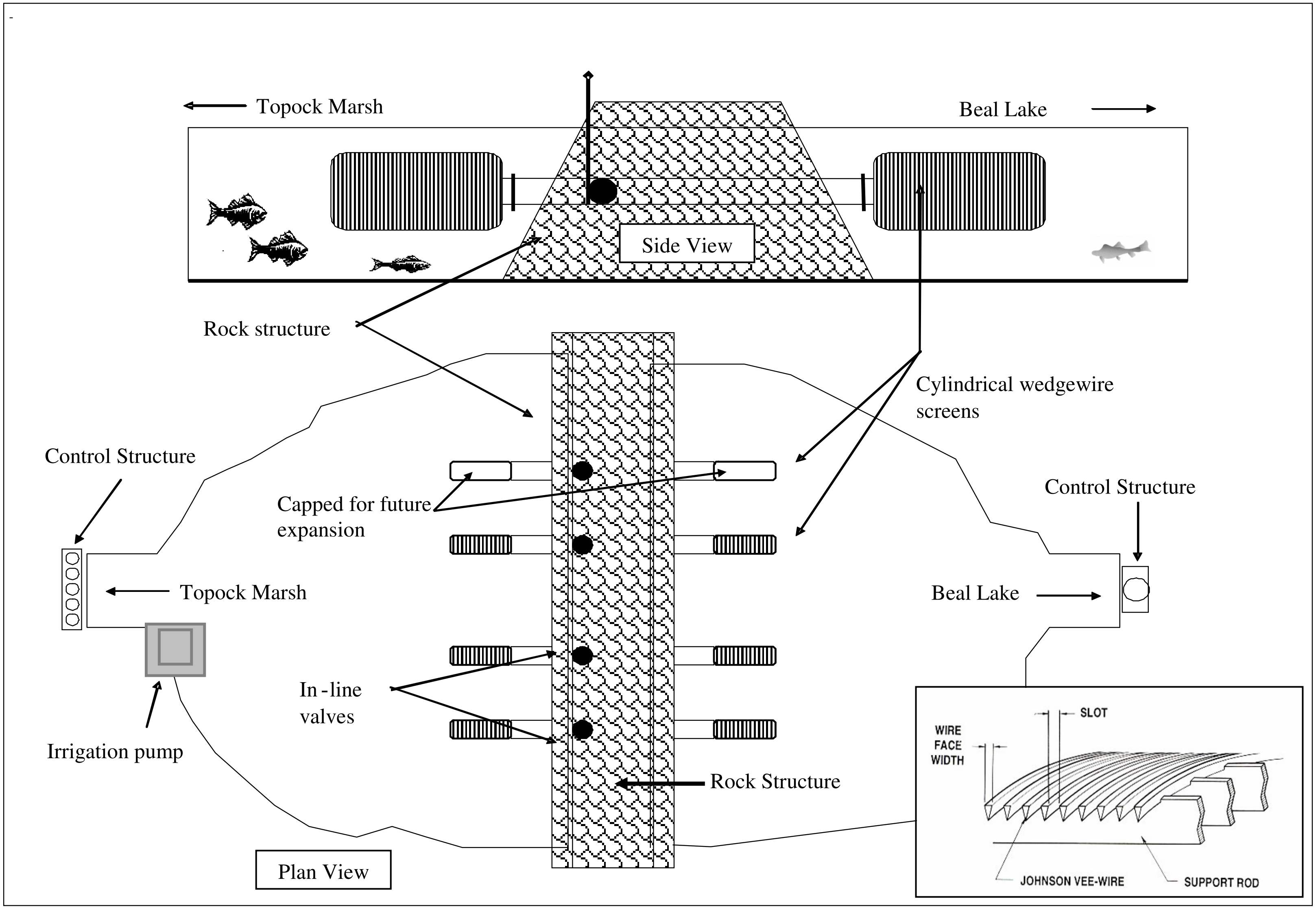


Figure 3. Plan view and side view schematics of the rock structure with installed prototype cylindrical wedge wire screen system. Insert depicts wedge-wire screen technology.

Figure 4. Remote water level monitoring system (SIT60) and attached solar panel installed on the western side of the rock structure.

Figure 5. Electromagnetic flow meter installed to measure water flow through the screened pipe system.

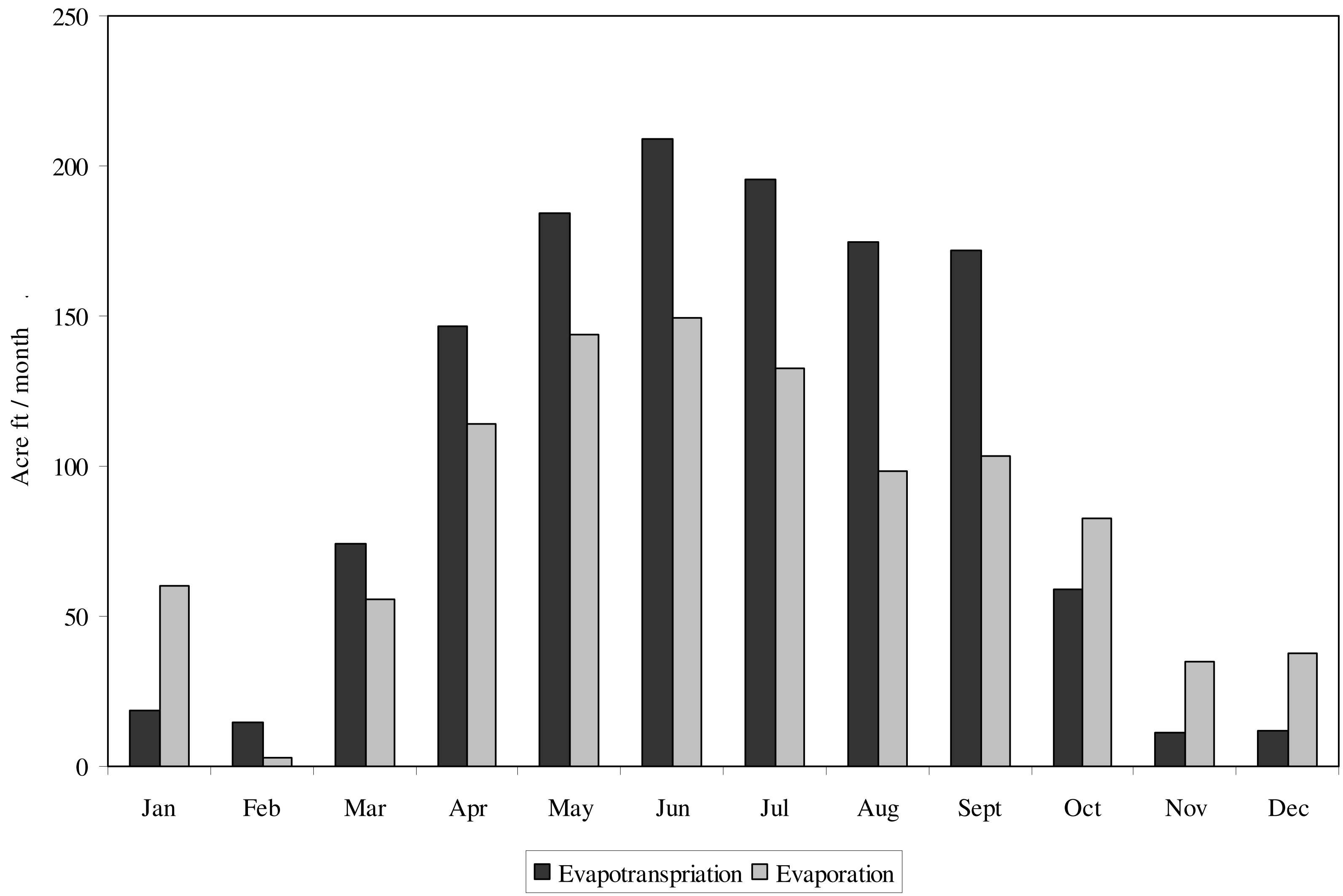


Figure 6. Comparison of monthly evapotranspiration and evaporation rates estimate by BOR (2003).

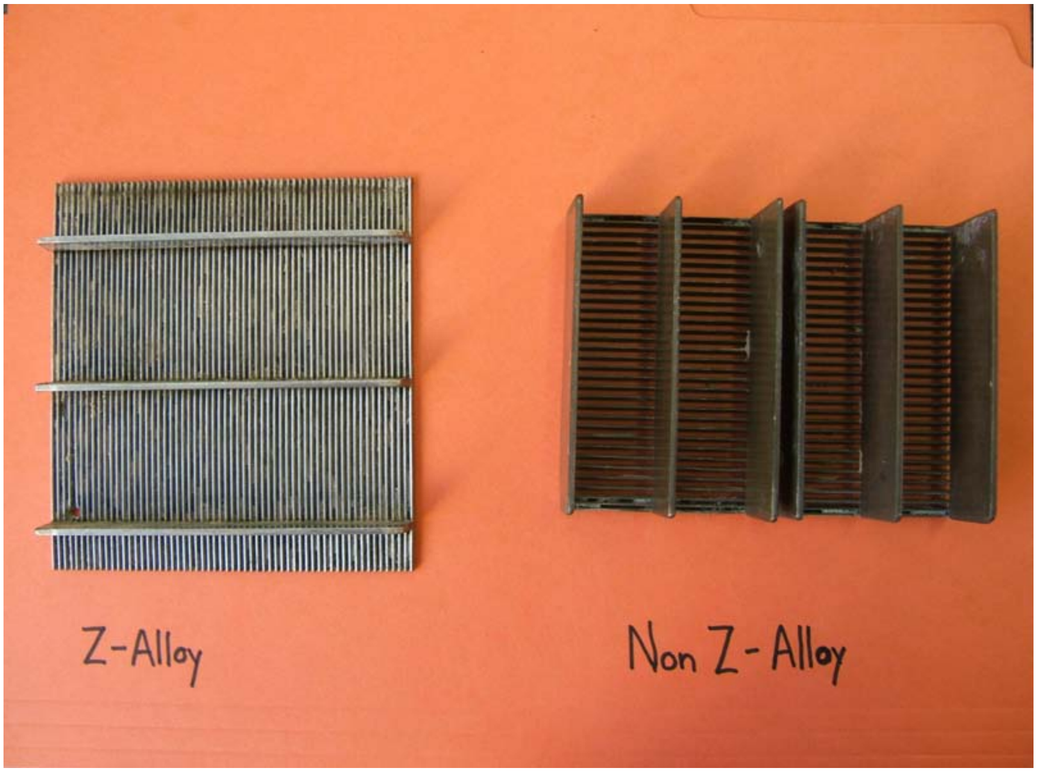


Figure 7. Z-Alloy and non-Z-Alloy samples installed side by side near the existing screened pipes.

Figure 8. Air compressor hose attached to screen backwash system.

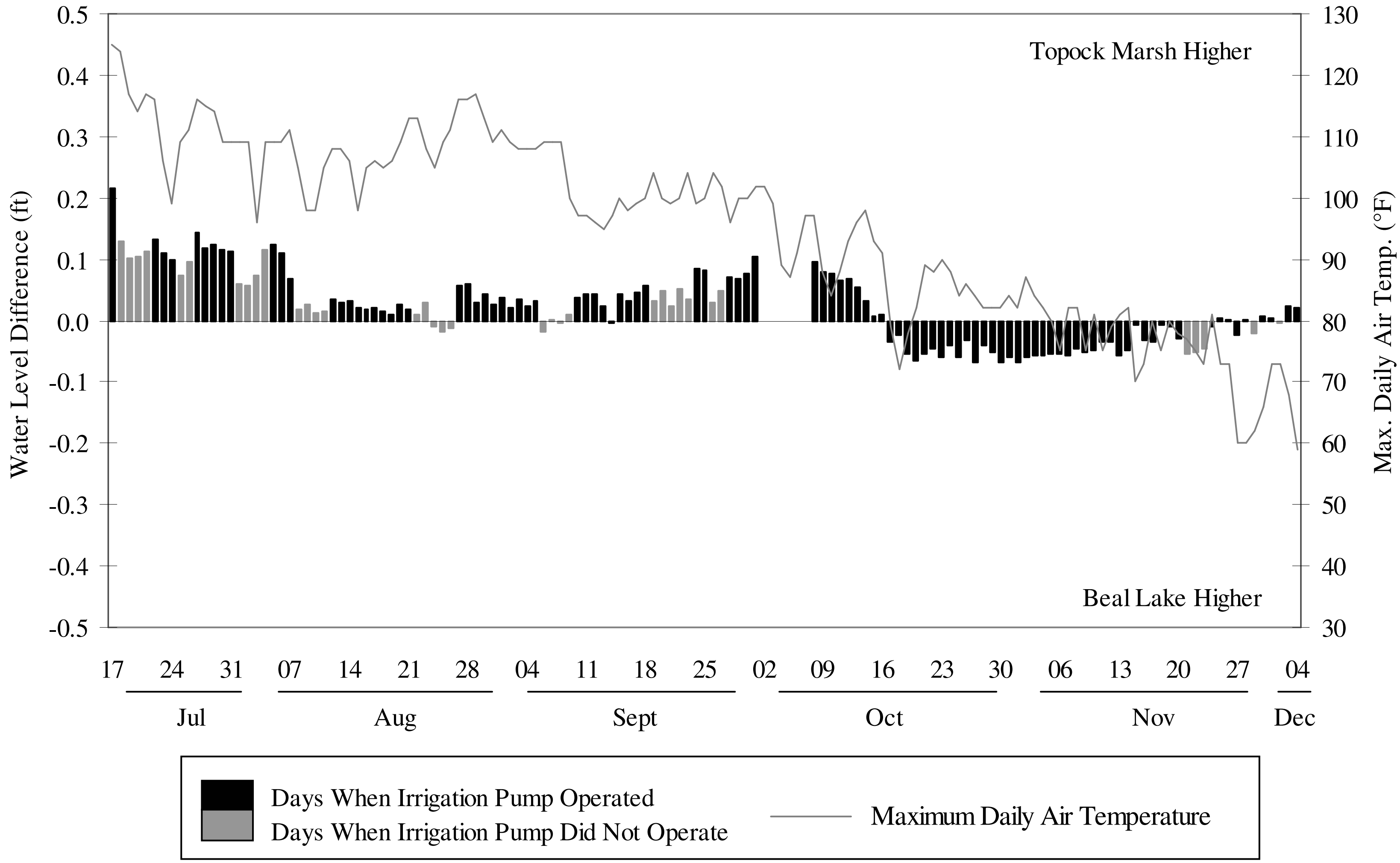


Figure 9. Mean daily water level difference and maximum daily air temperature between Topock Marsh and Beal Lake, mid-July through early December, 2005. Water level differences during fall sampling period (2 Oct to 7 Oct) were removed from analysis. (Scale for water level difference is in tenths of feet).

Figure 10. Mean daily water temperature recorded at the remote monitoring system from mid-July to early December, 2005.

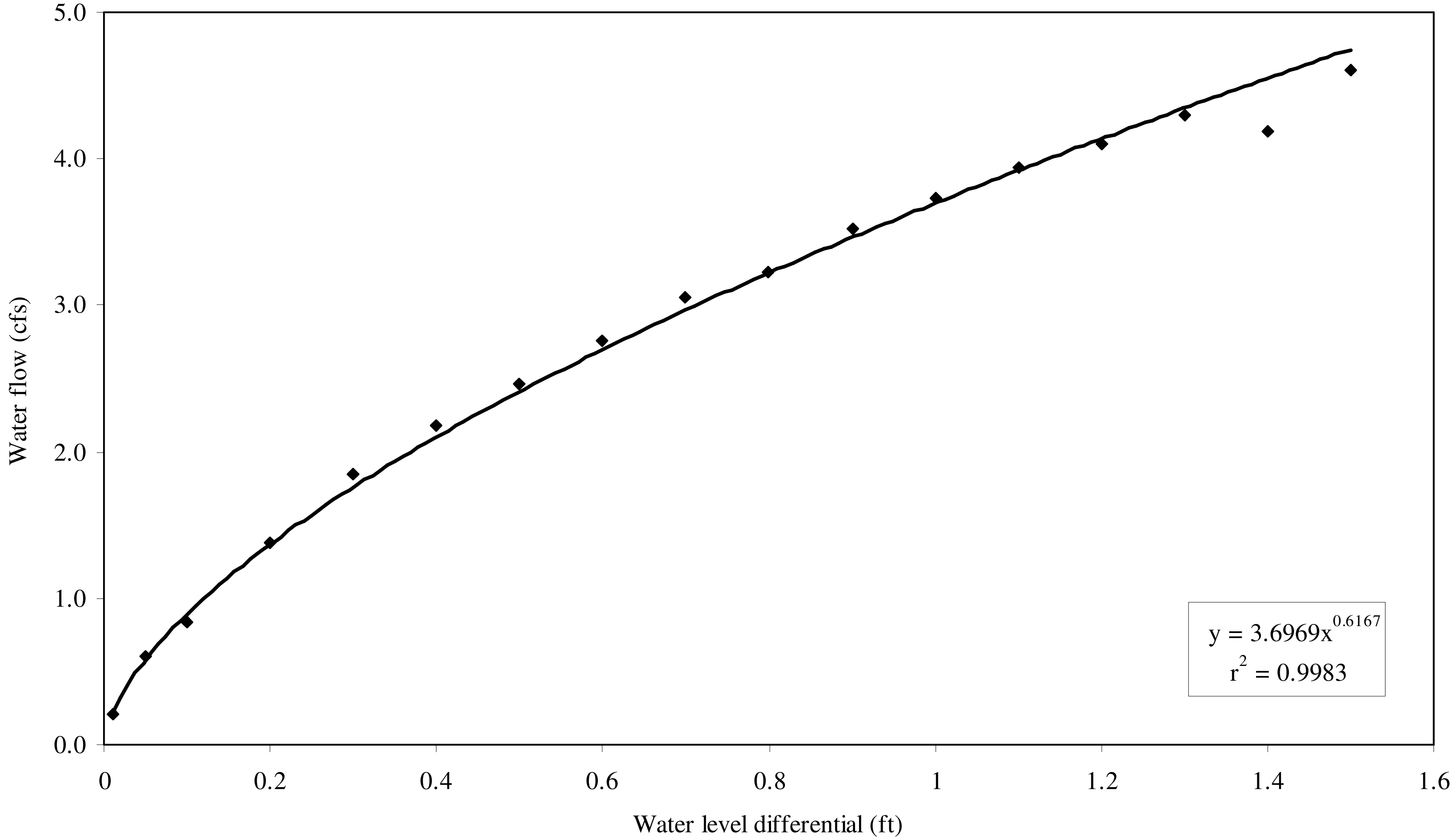


Figure 11. Water flow through the screened pipe as a function of head differential between Topock Marsh and Beal Lake.

Figure 12. Sediment plume originating from submerged screens during the air backwater test.

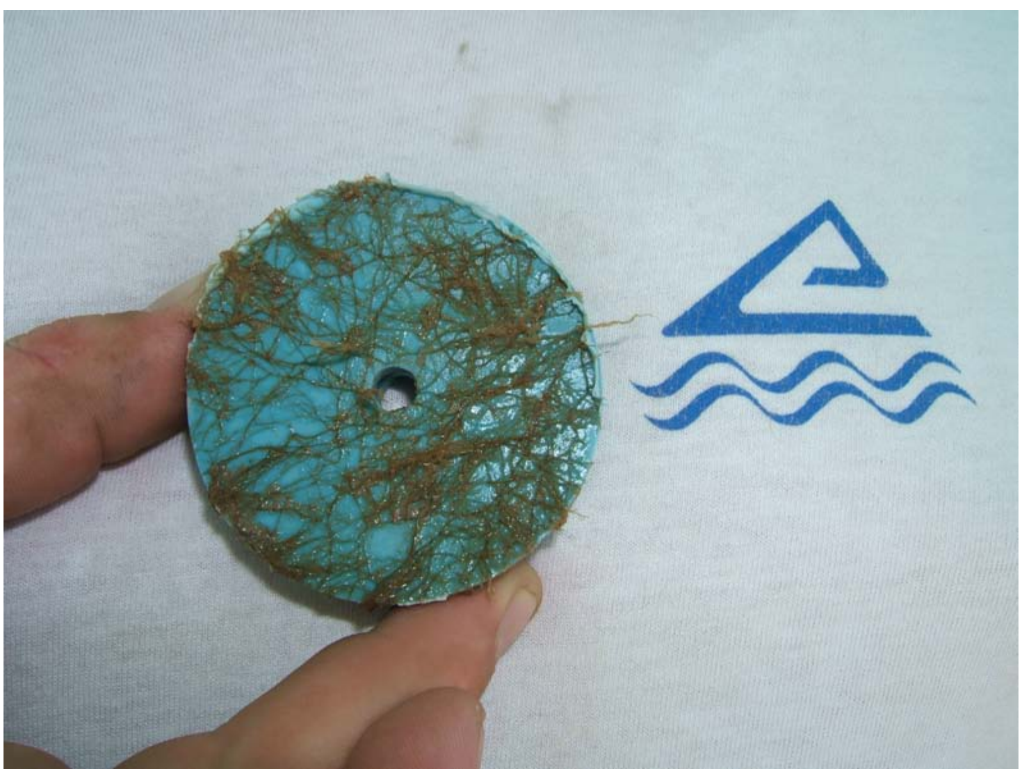
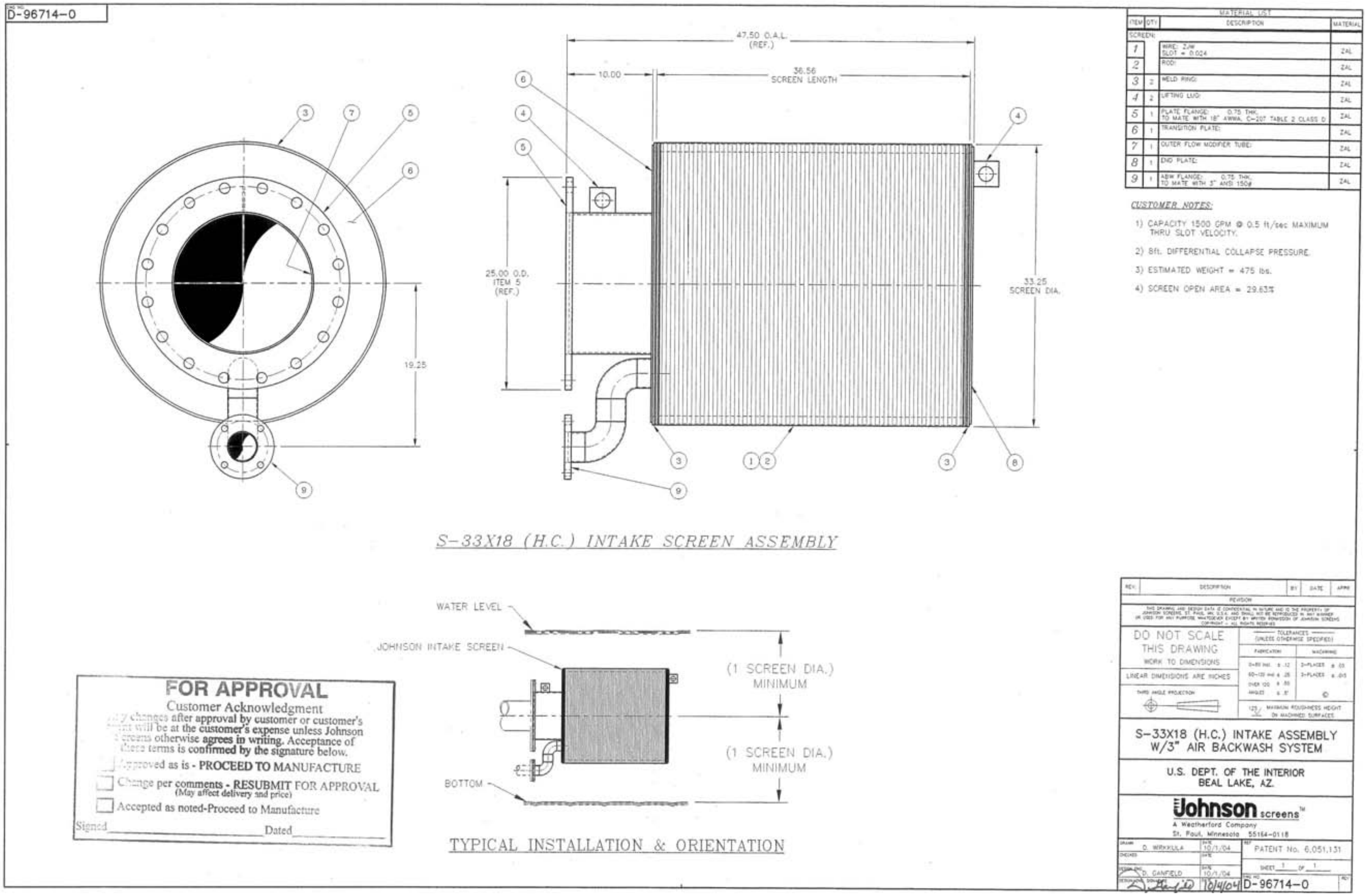


Figure 13. Colonial hydrozoa from the genus Cordylophera attached to the inside of a section of PVC pipe removed during the installation of the flow meter.

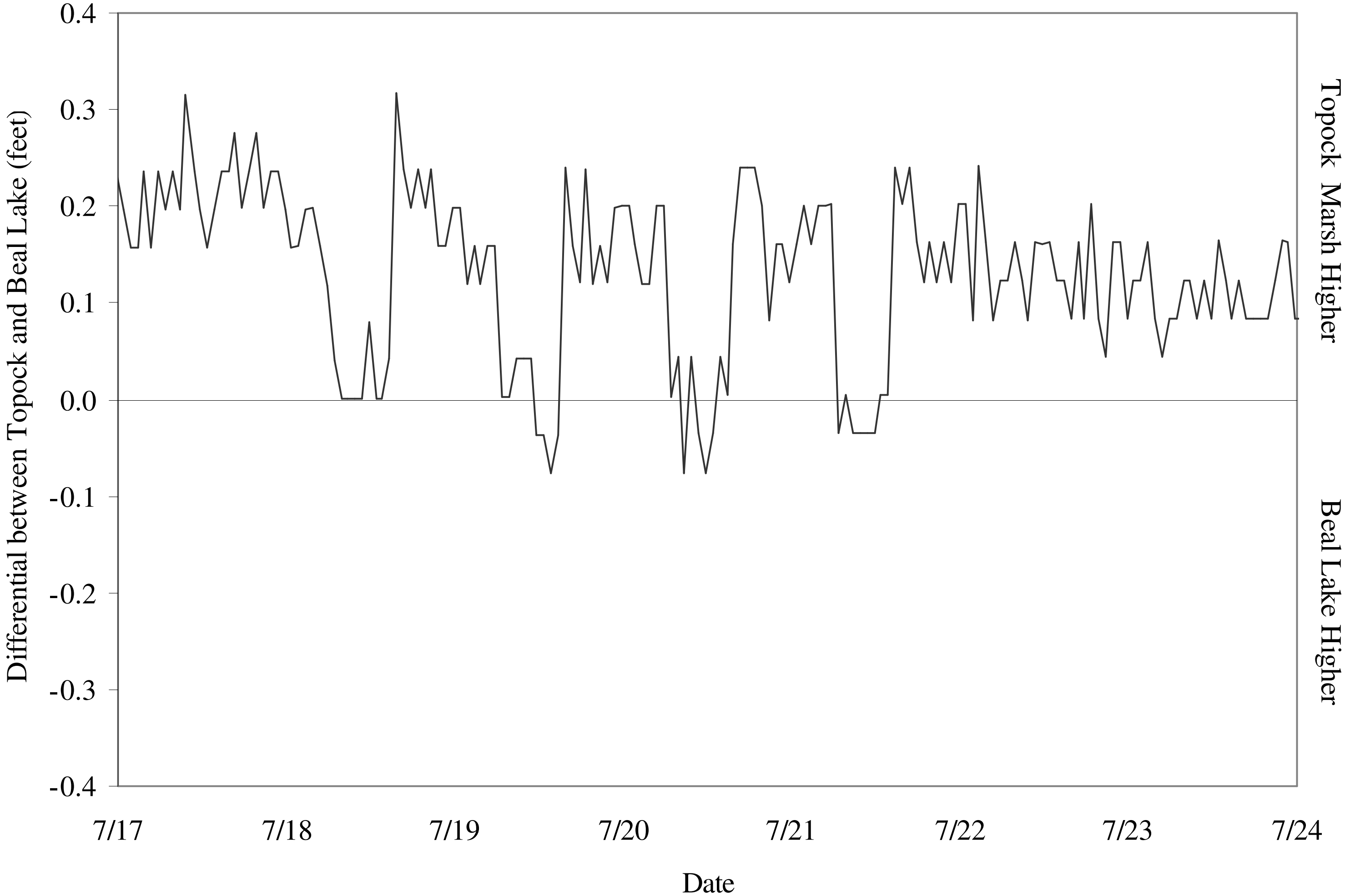
Figure 14. Water permeating through the rock structure.

Figure 15. Box-culvert located in the channel connecting the rock structure to Beal Lake.

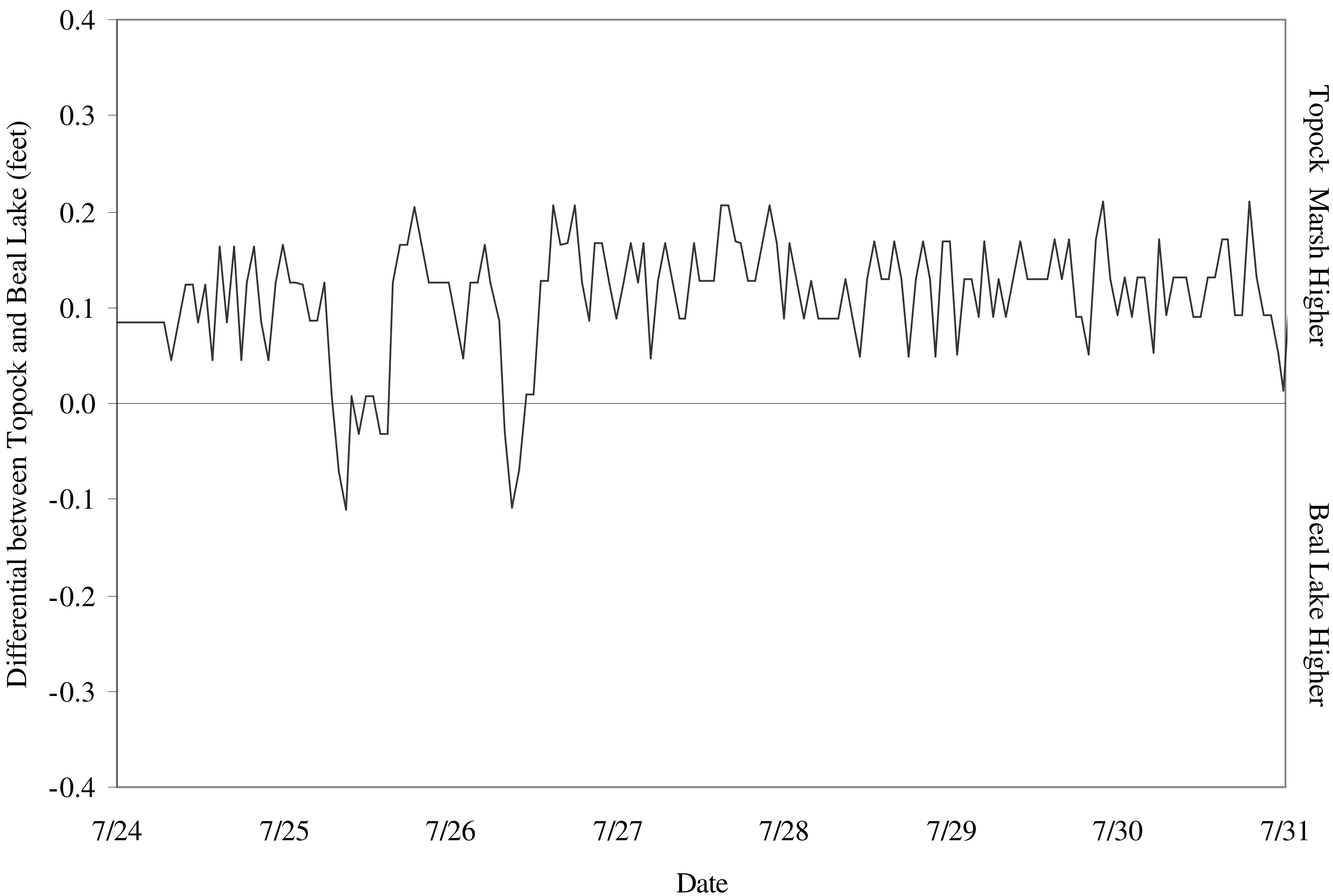
APPENDICES



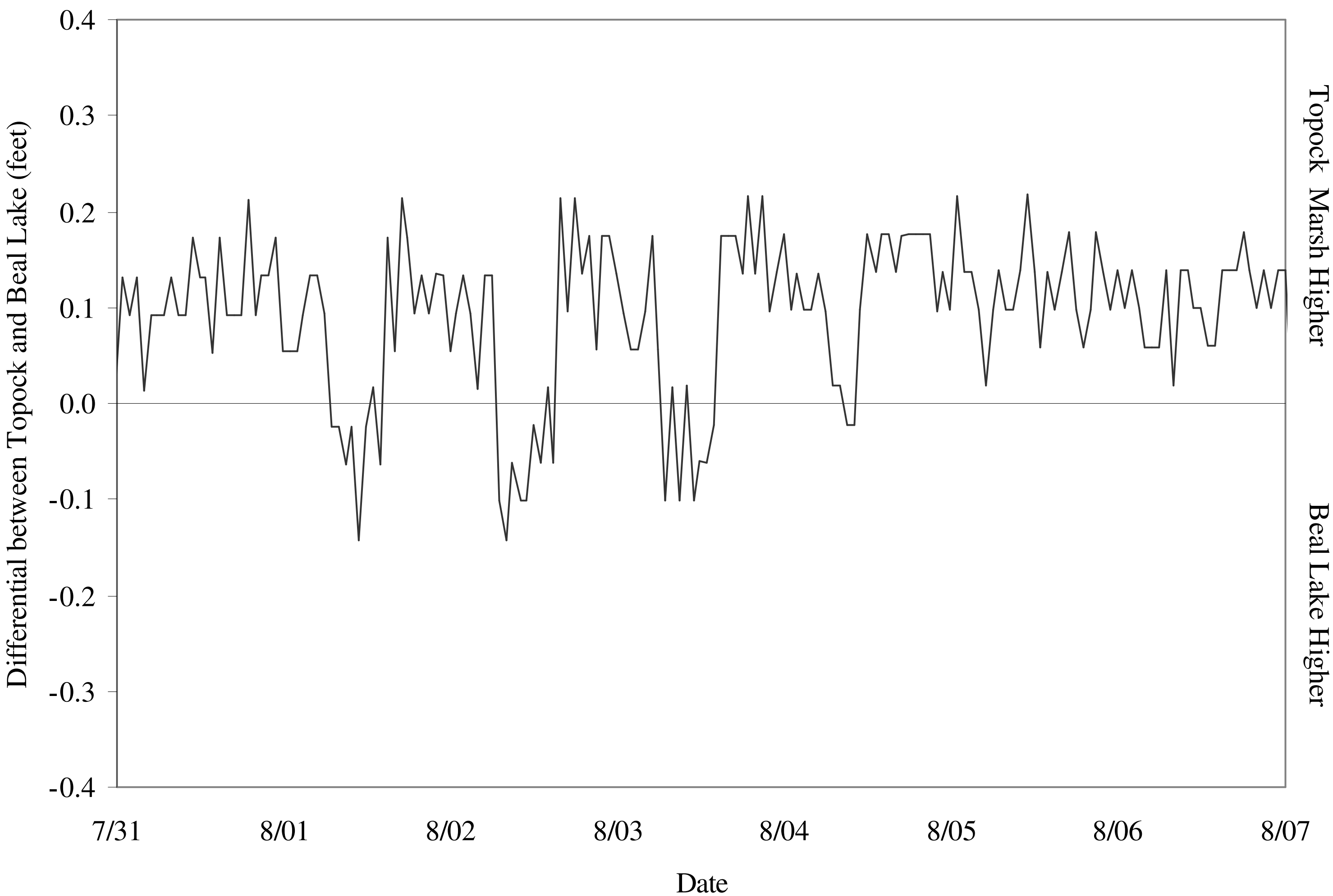
Appendix A. Cylindrical wedge-wire screen drawing and specifications.



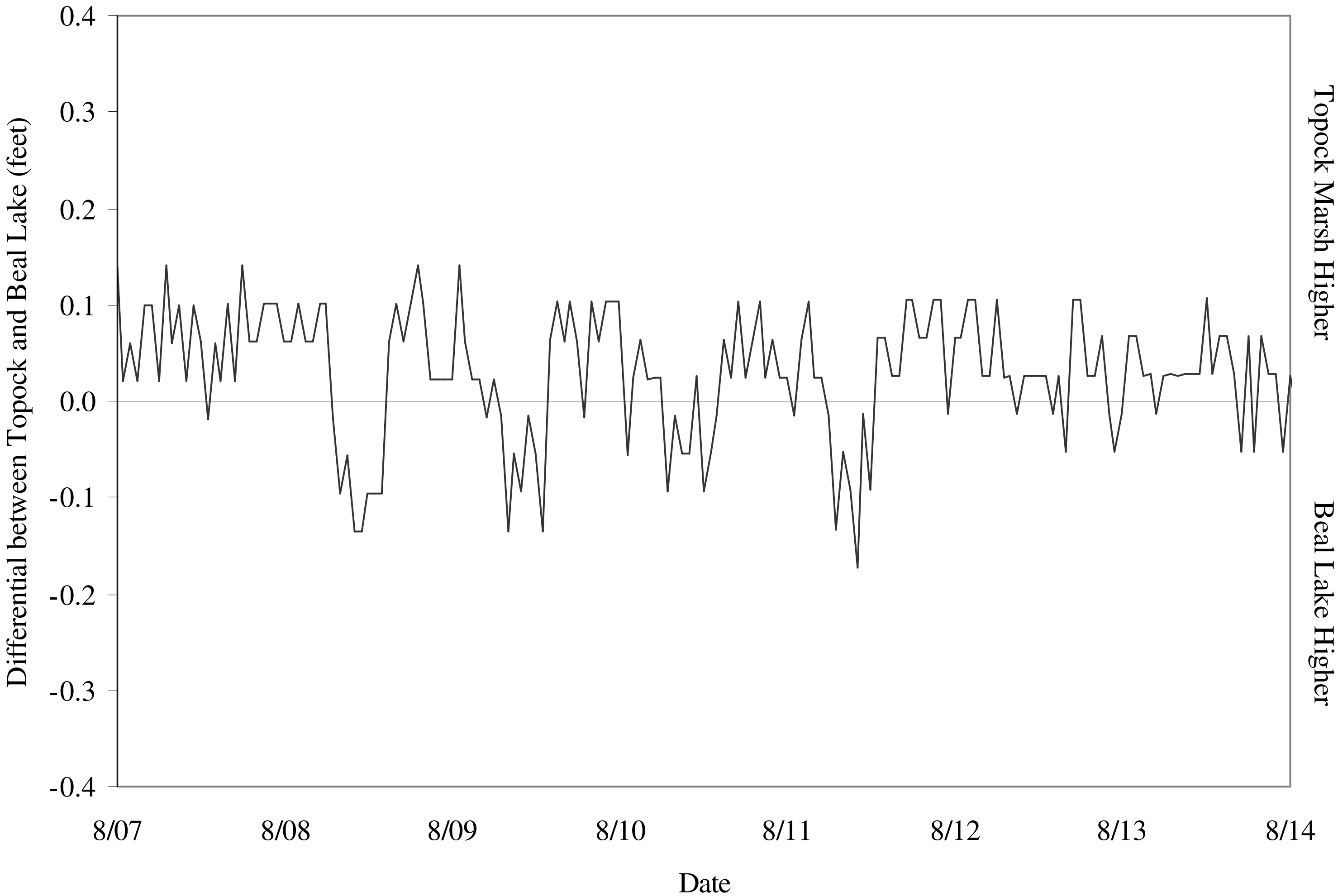
Appendix B. Water level differential between Topock Marsh and Beal Lake for the week of 17 July, 2005.



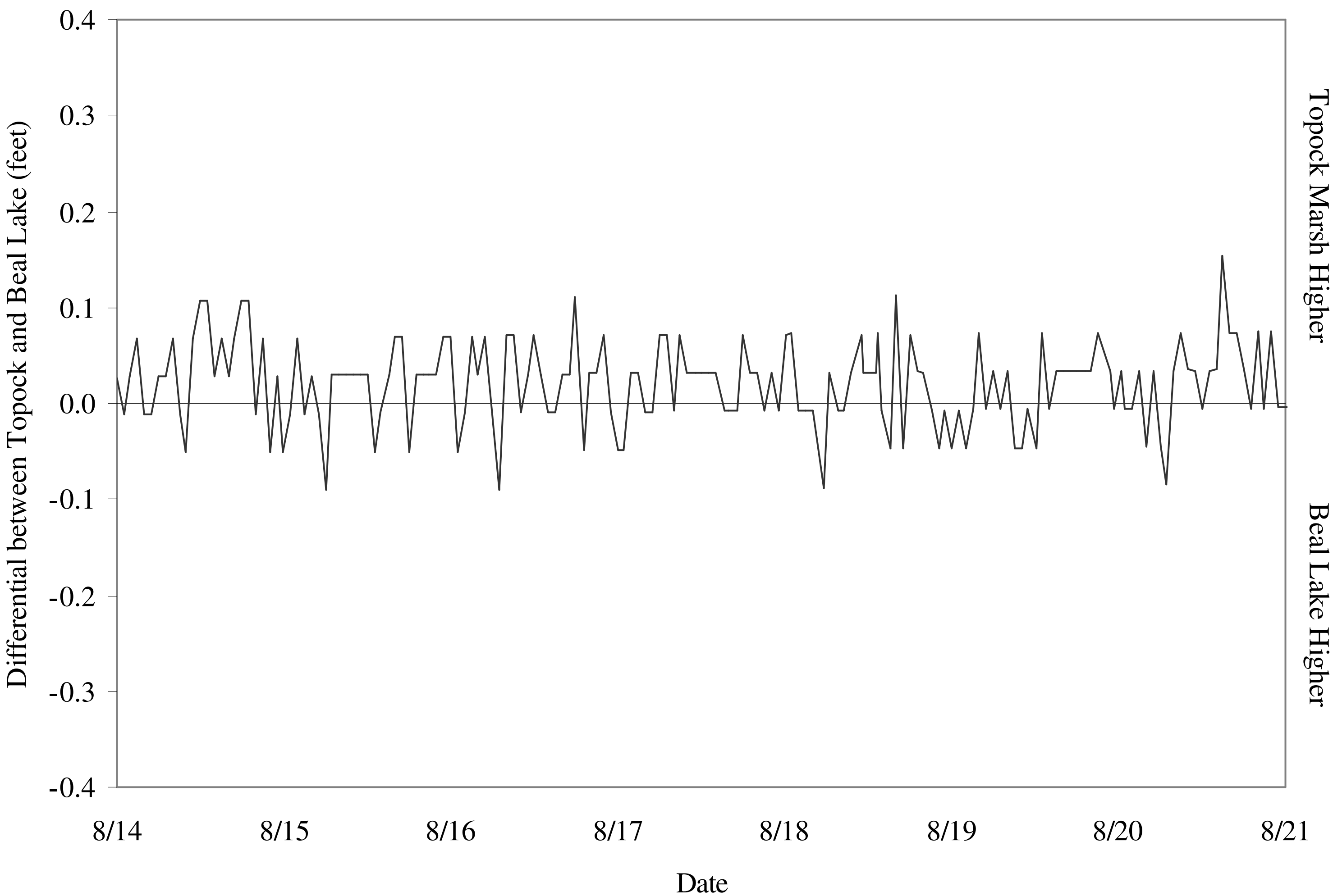
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 24 July, 2005.



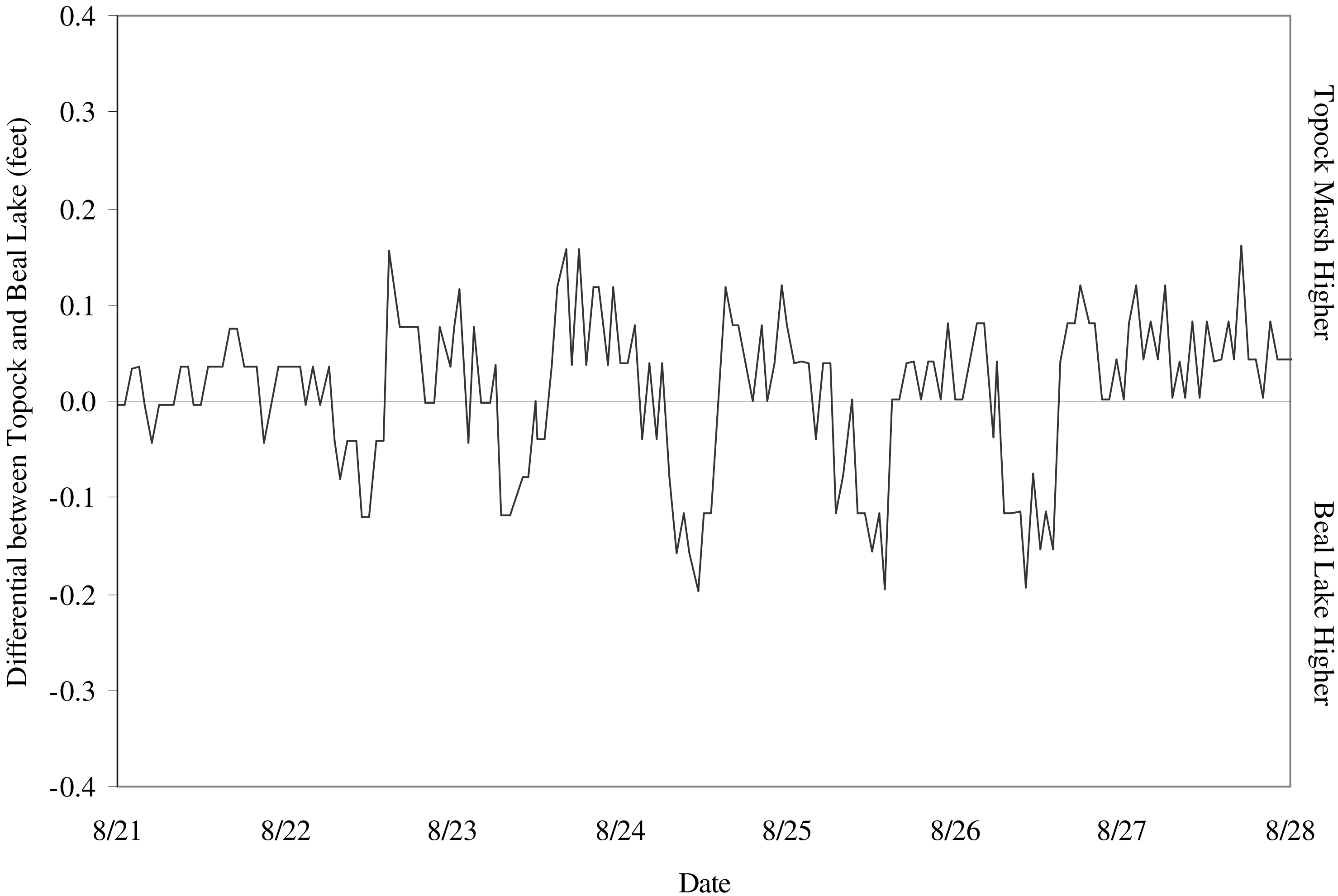
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 31 July, 2005.



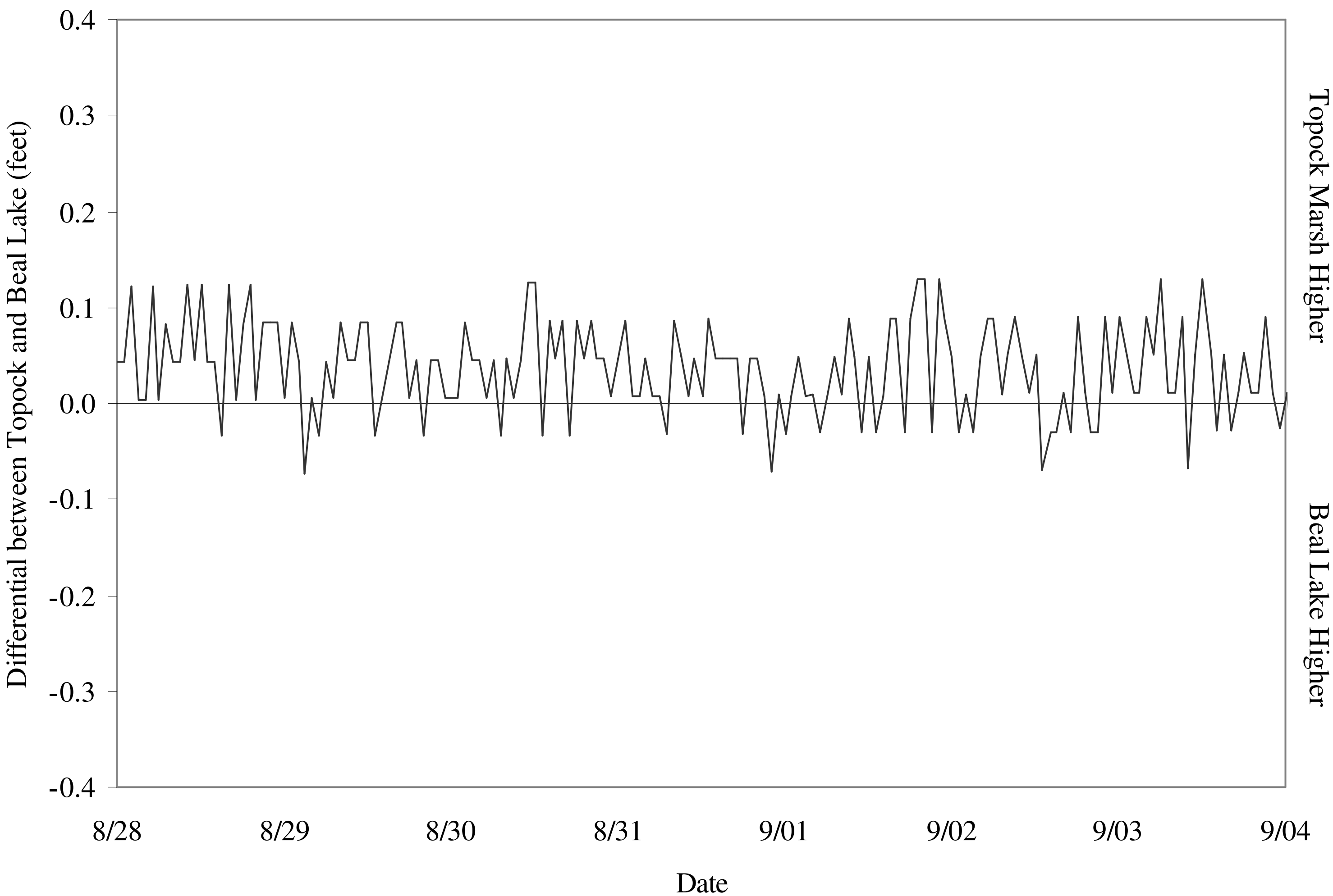
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 7 August, 2005.



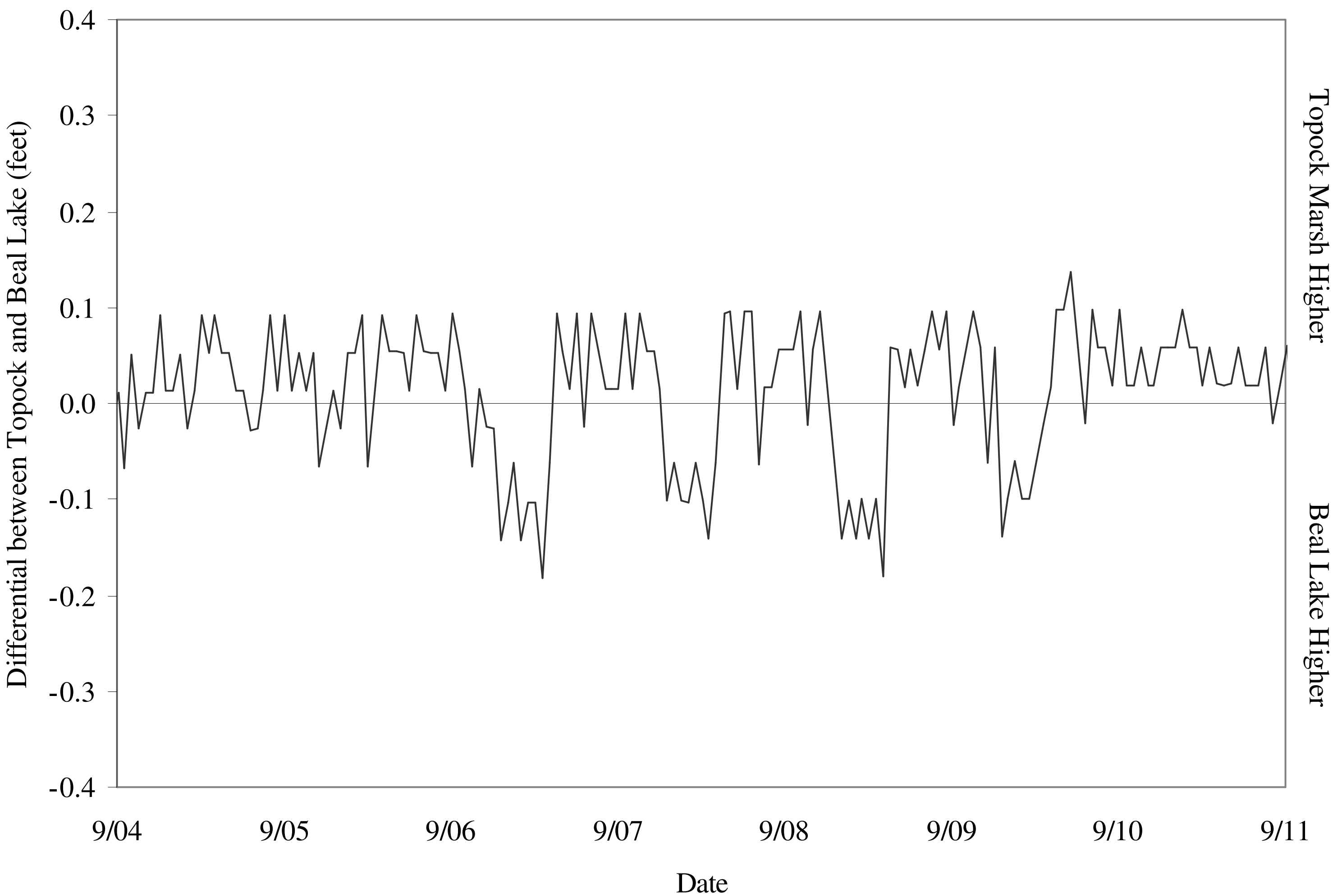
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 14 August, 2005.



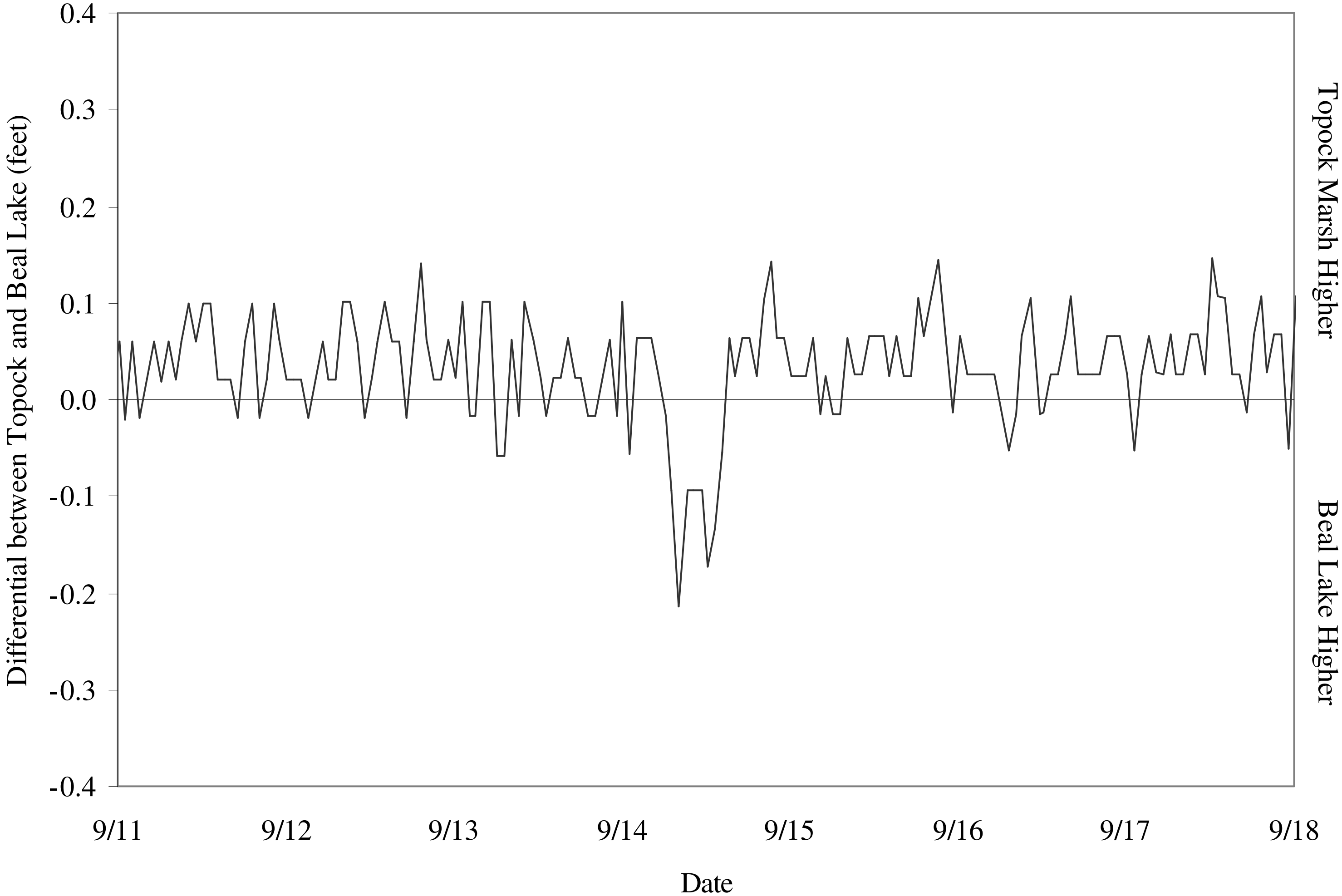
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 21 August, 2005.



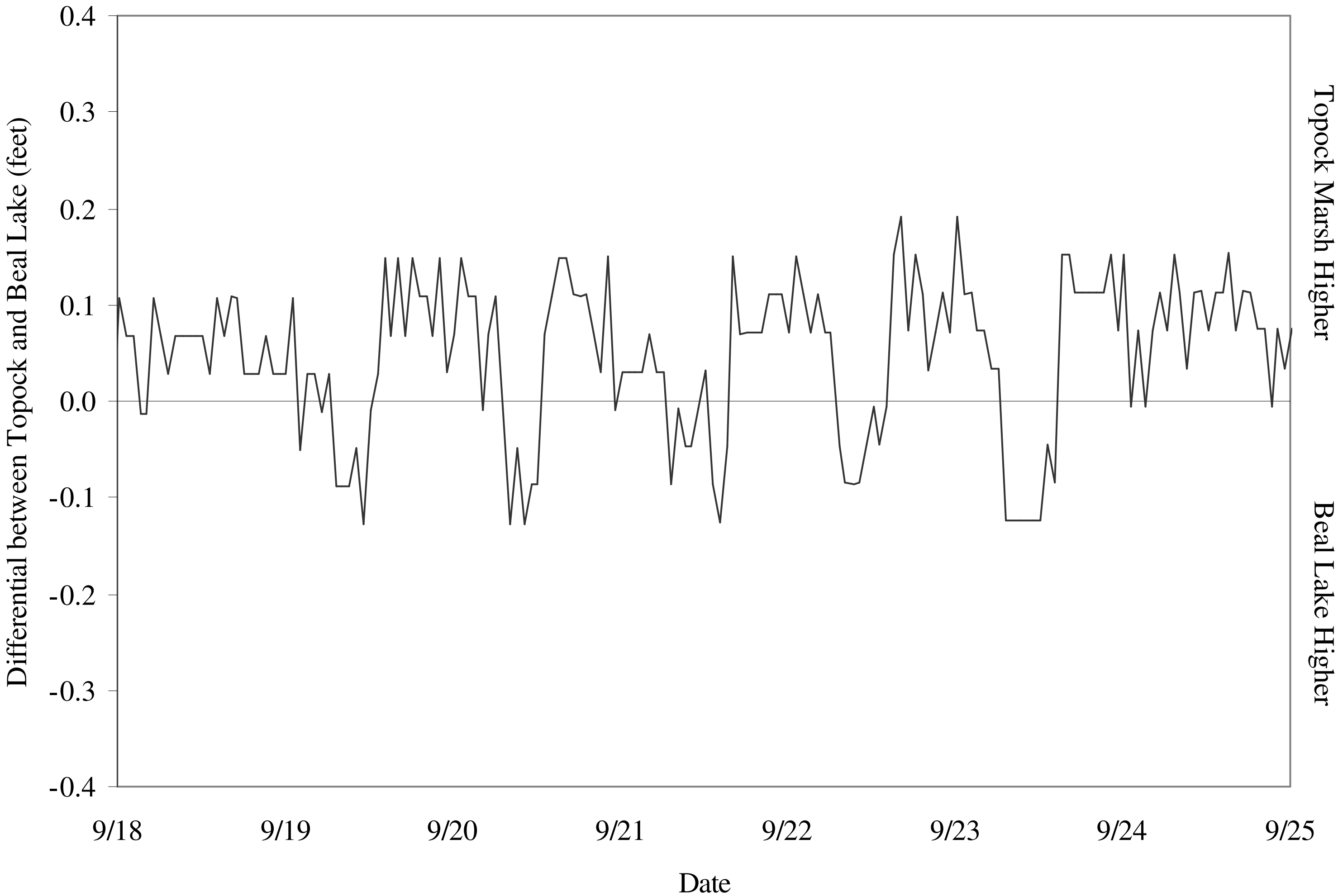
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 28 August, 2005.



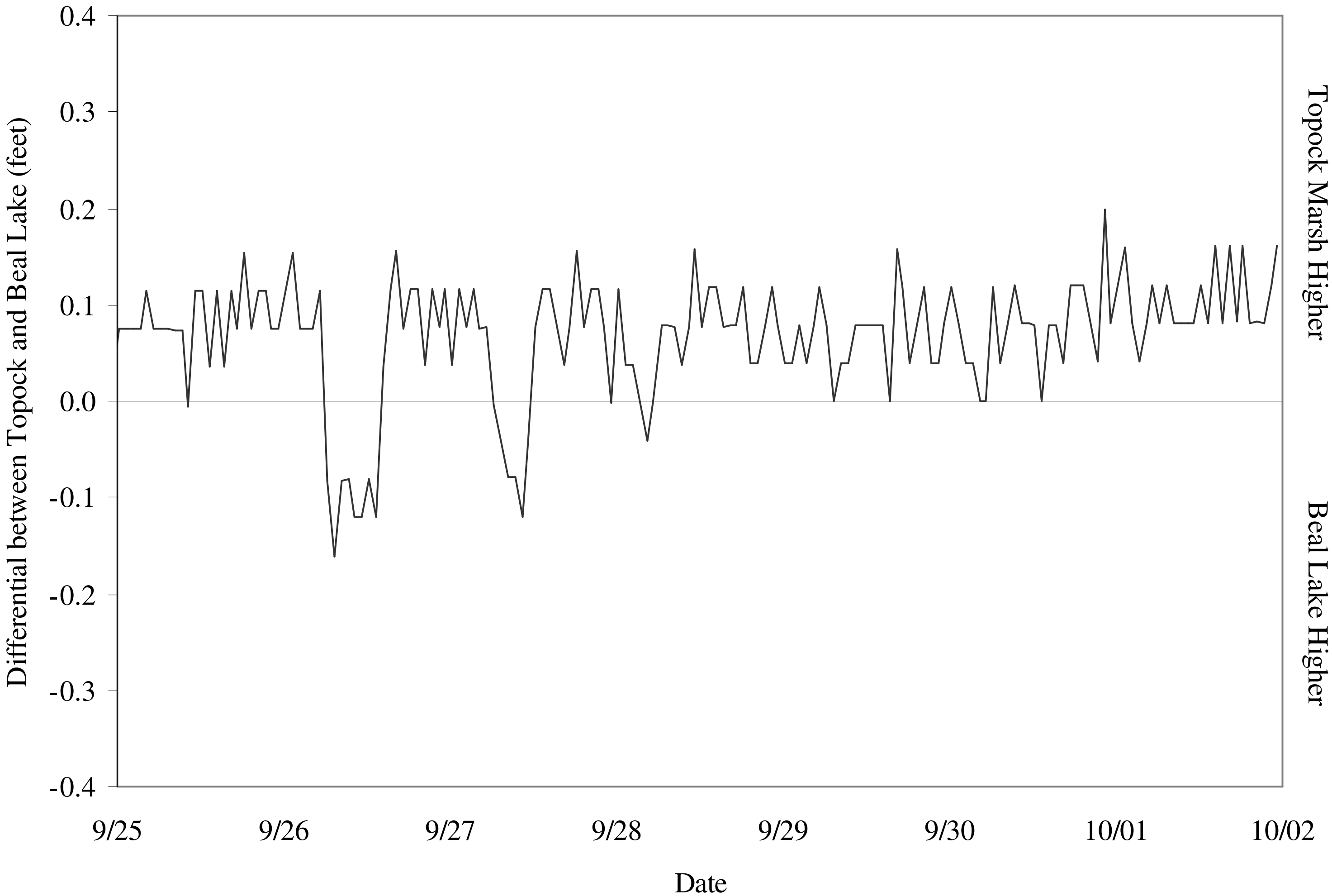
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 4 September, 2005.



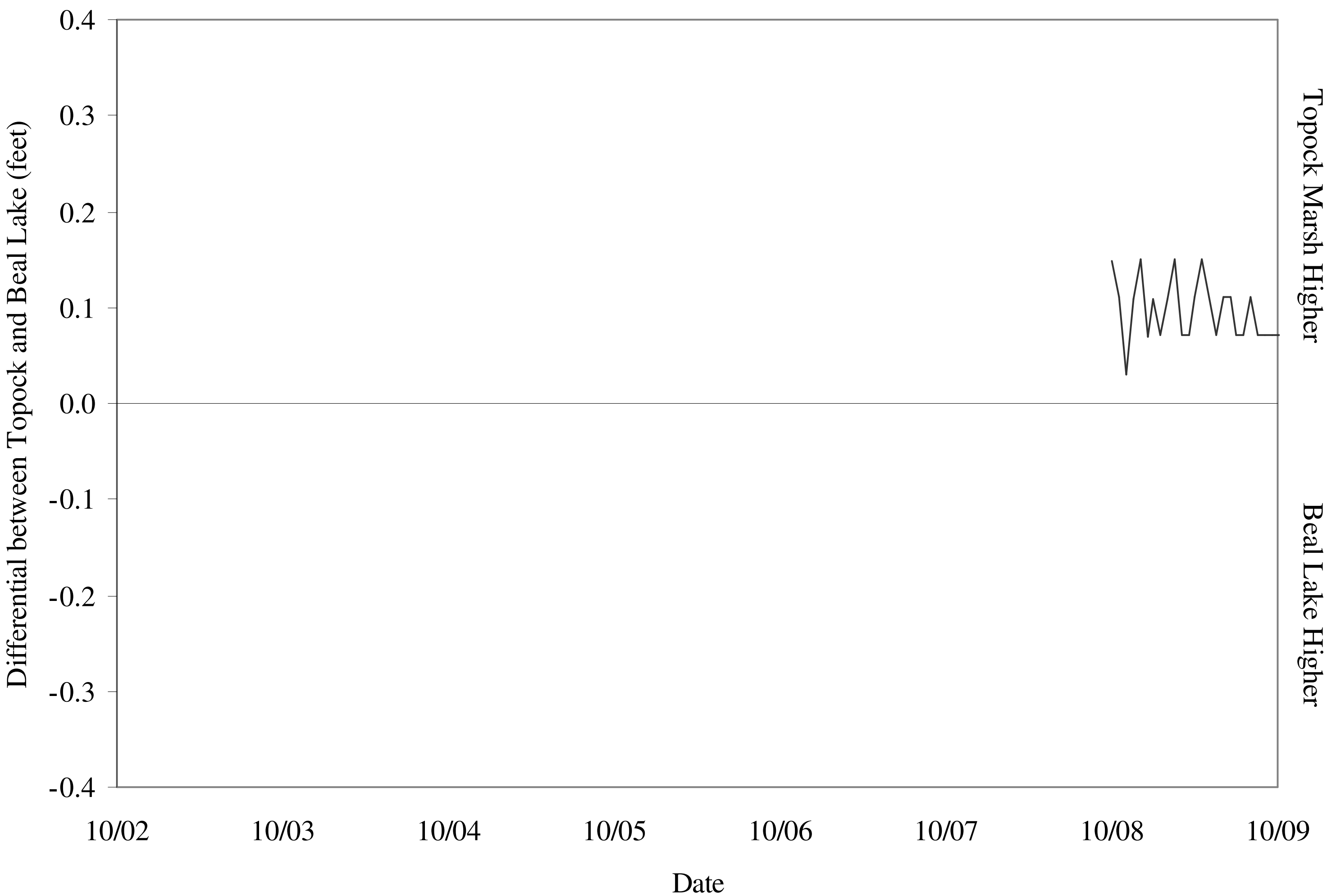
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 11 September, 2005.



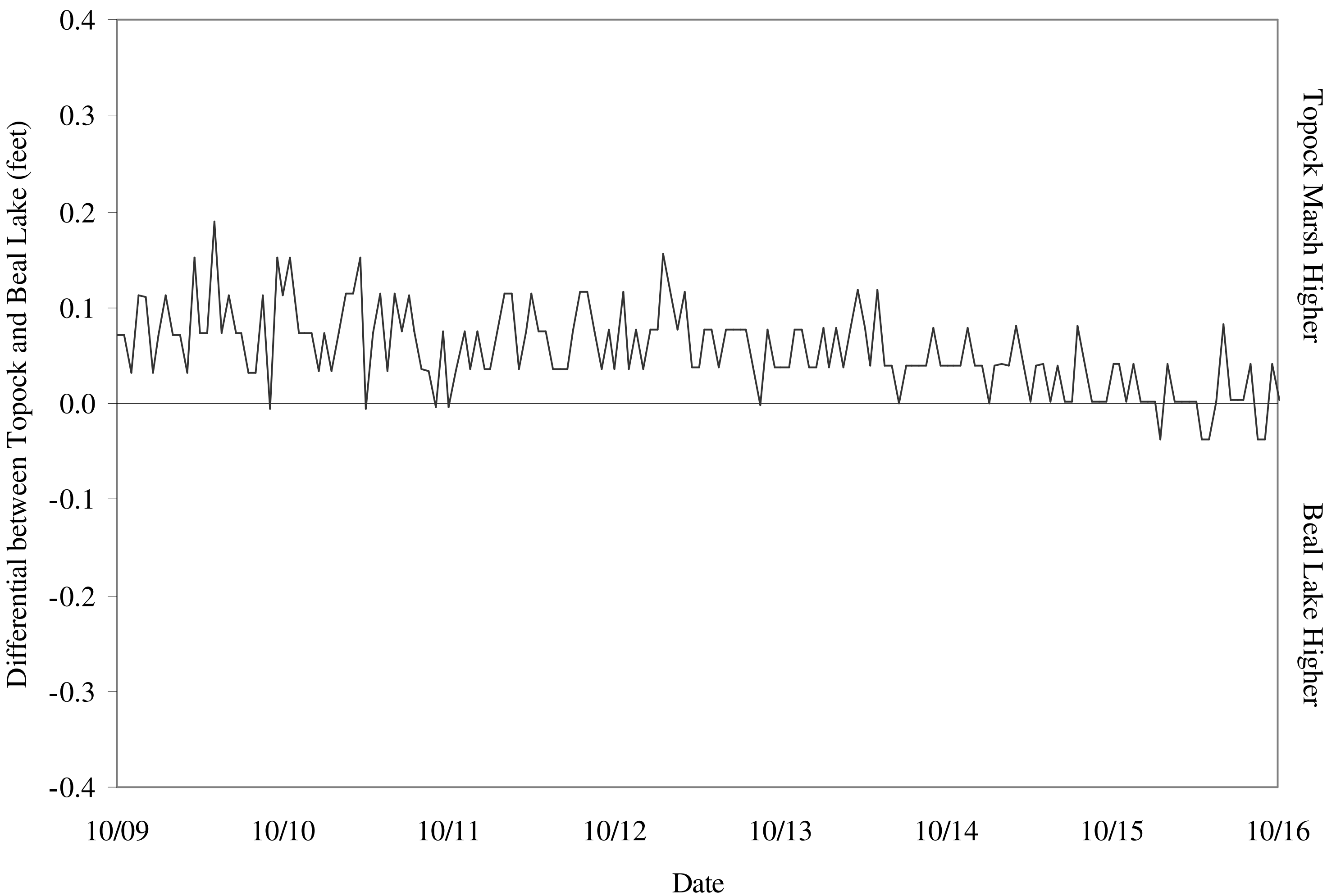
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 18 September, 2005.



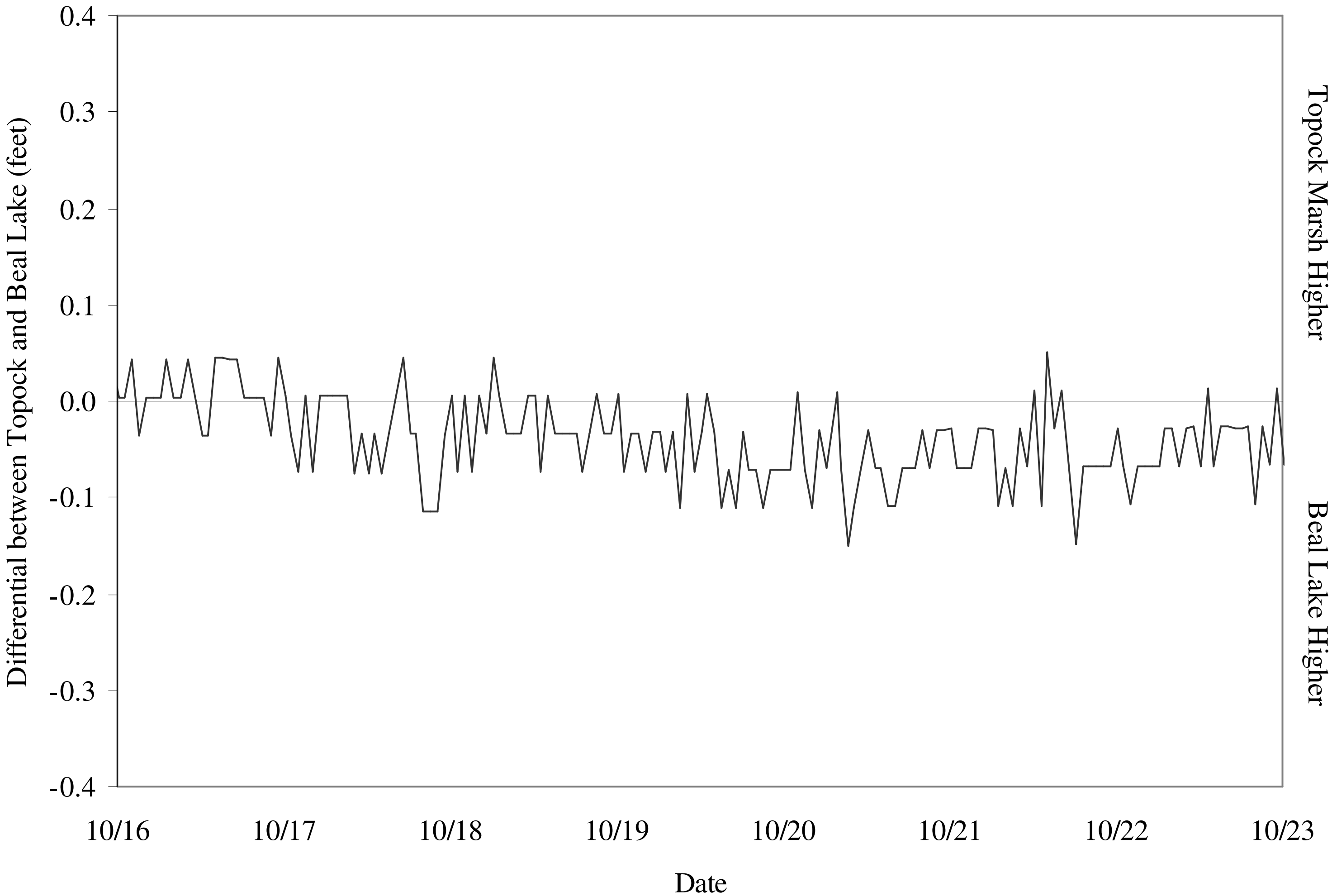
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 25 September, 2005.



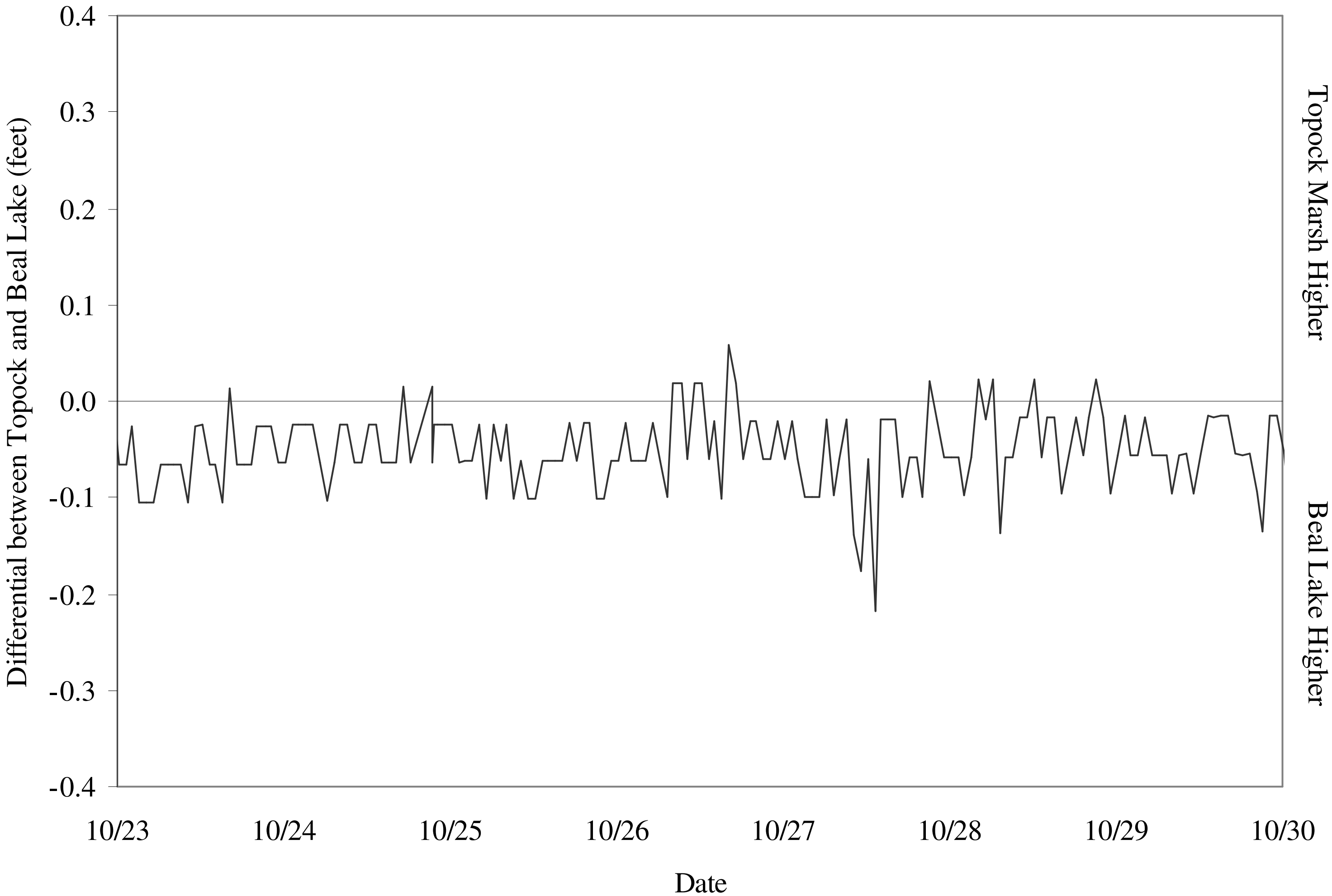
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 2 October, 2005.



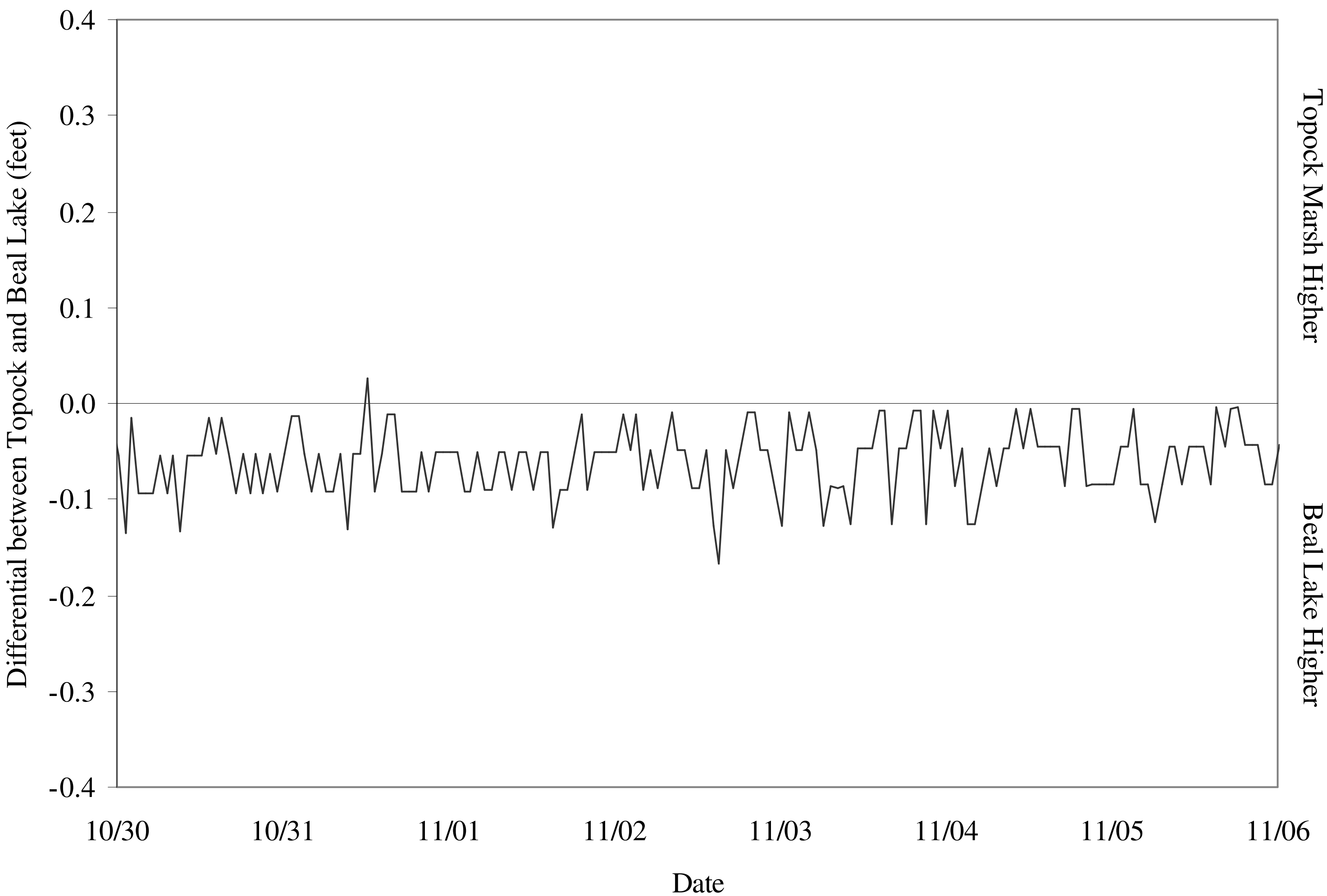
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 9 October, 2005.



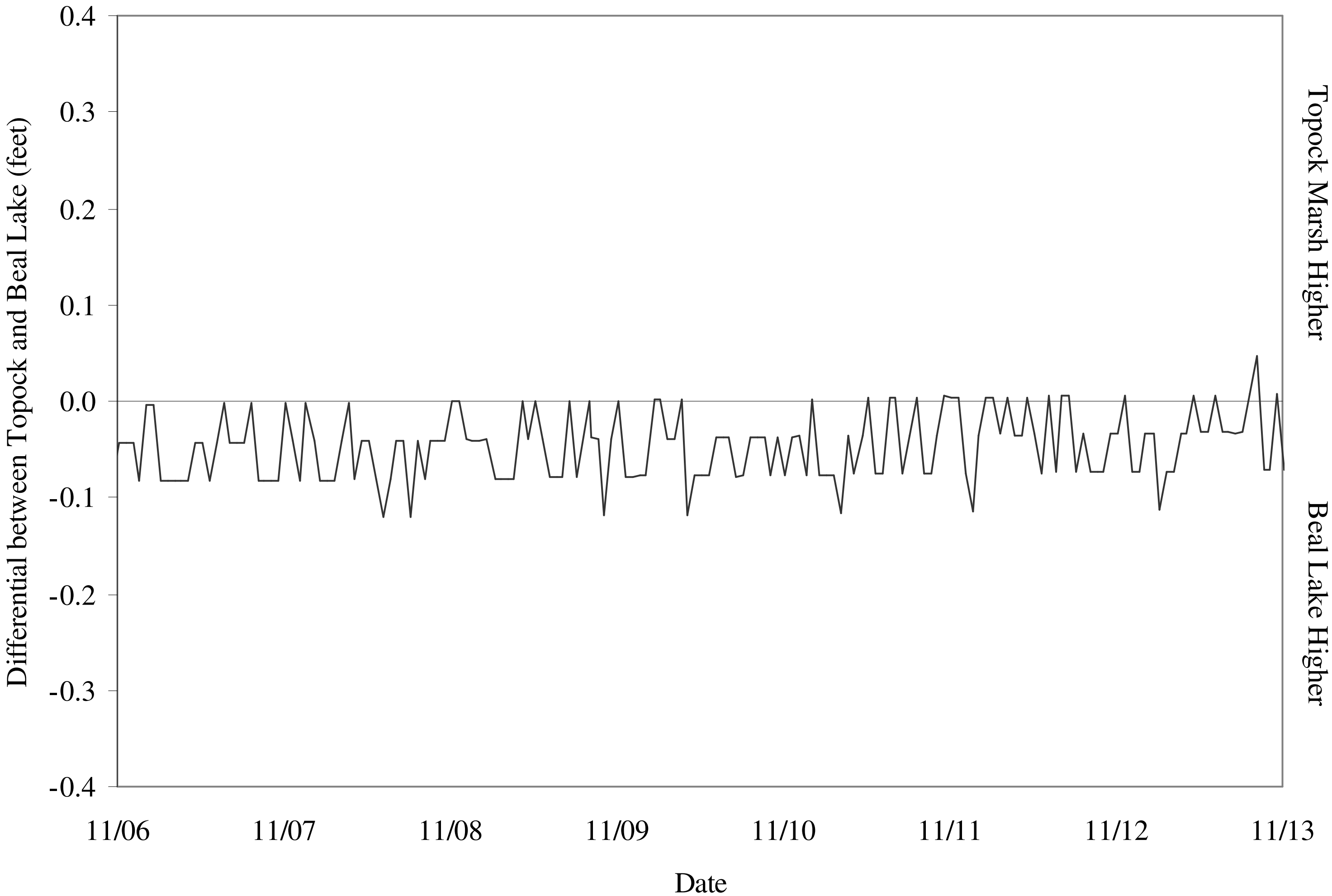
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 16 October, 2005.



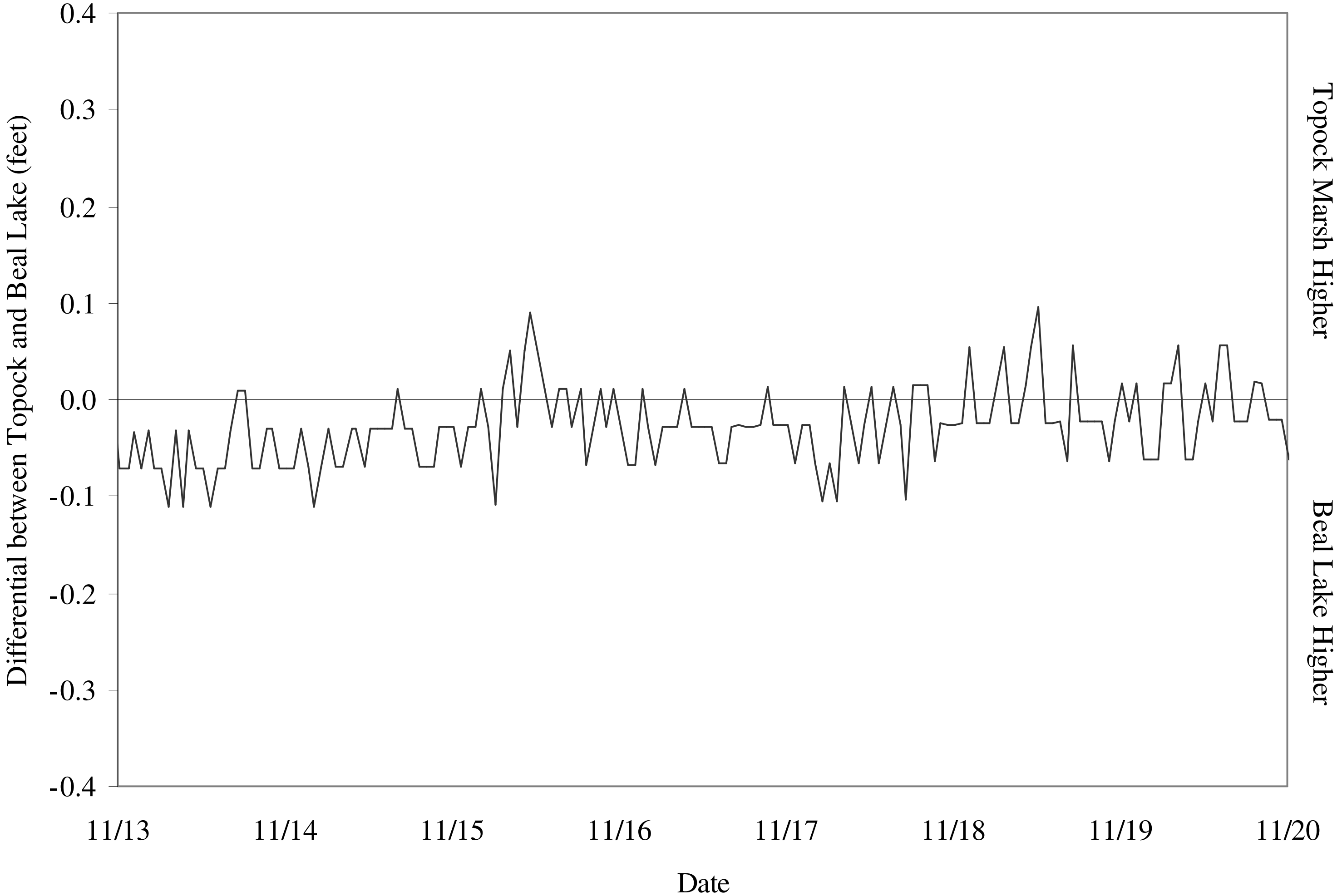
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 23 October, 2005.



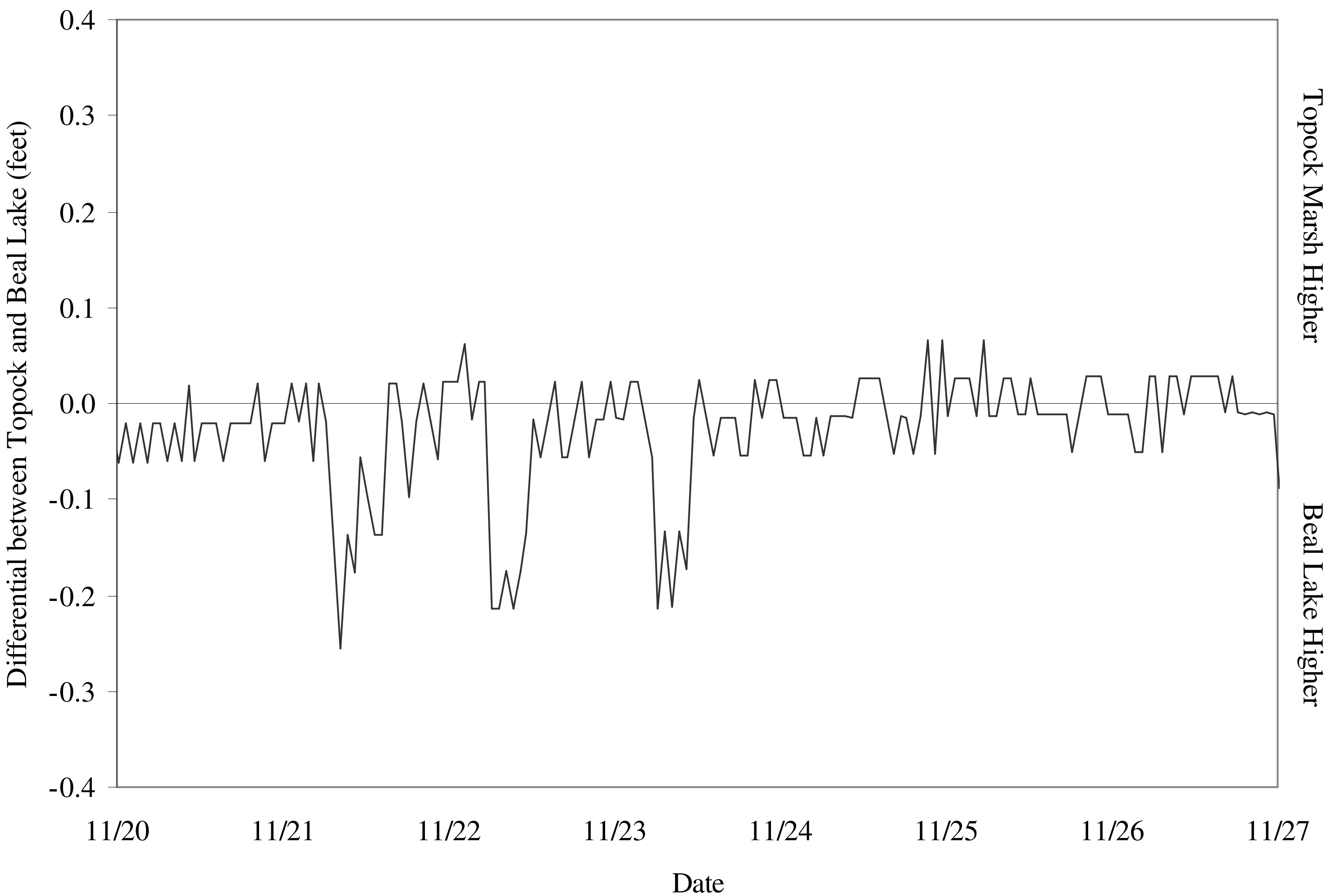
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 30 October, 2005.



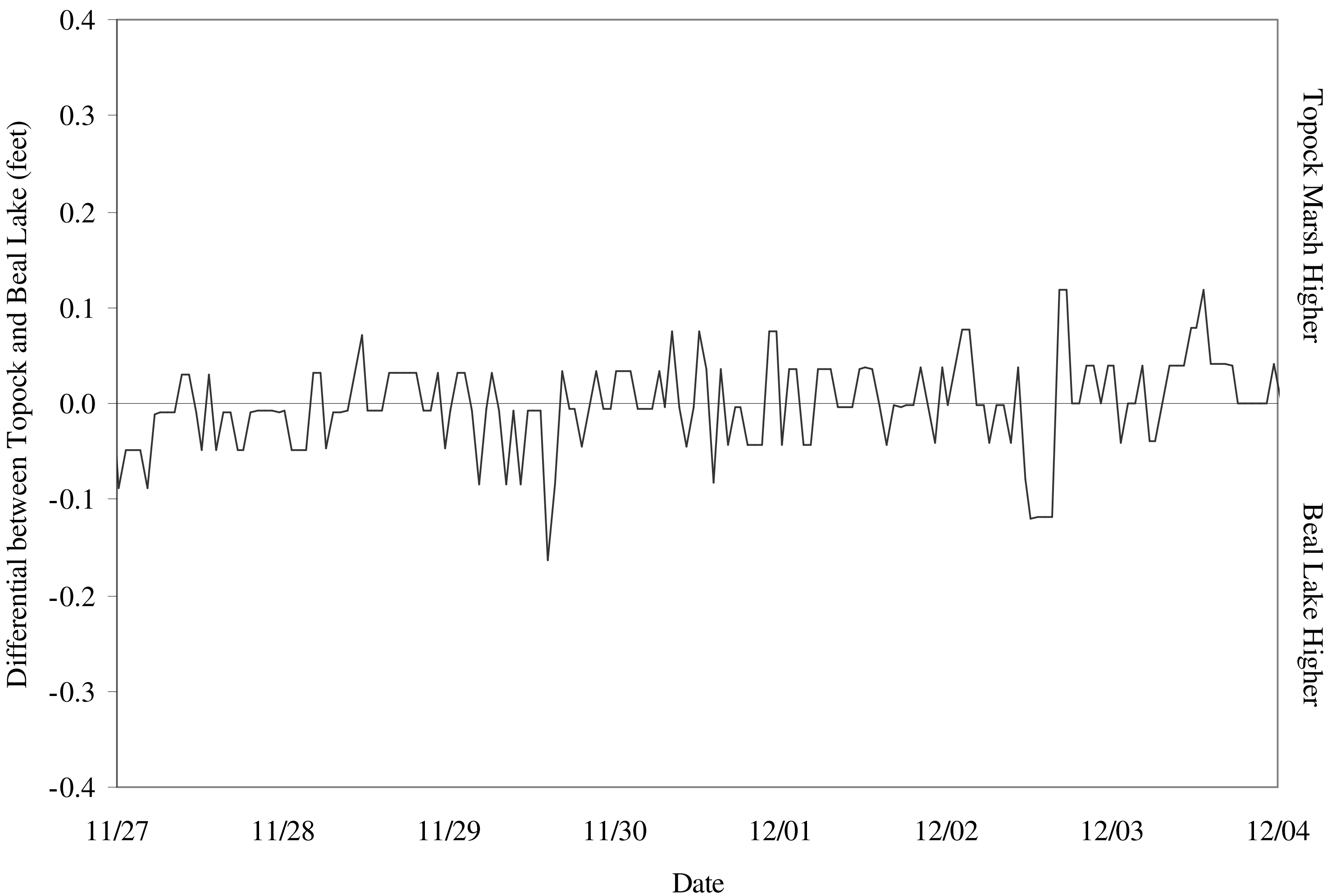
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 6 November, 2005.



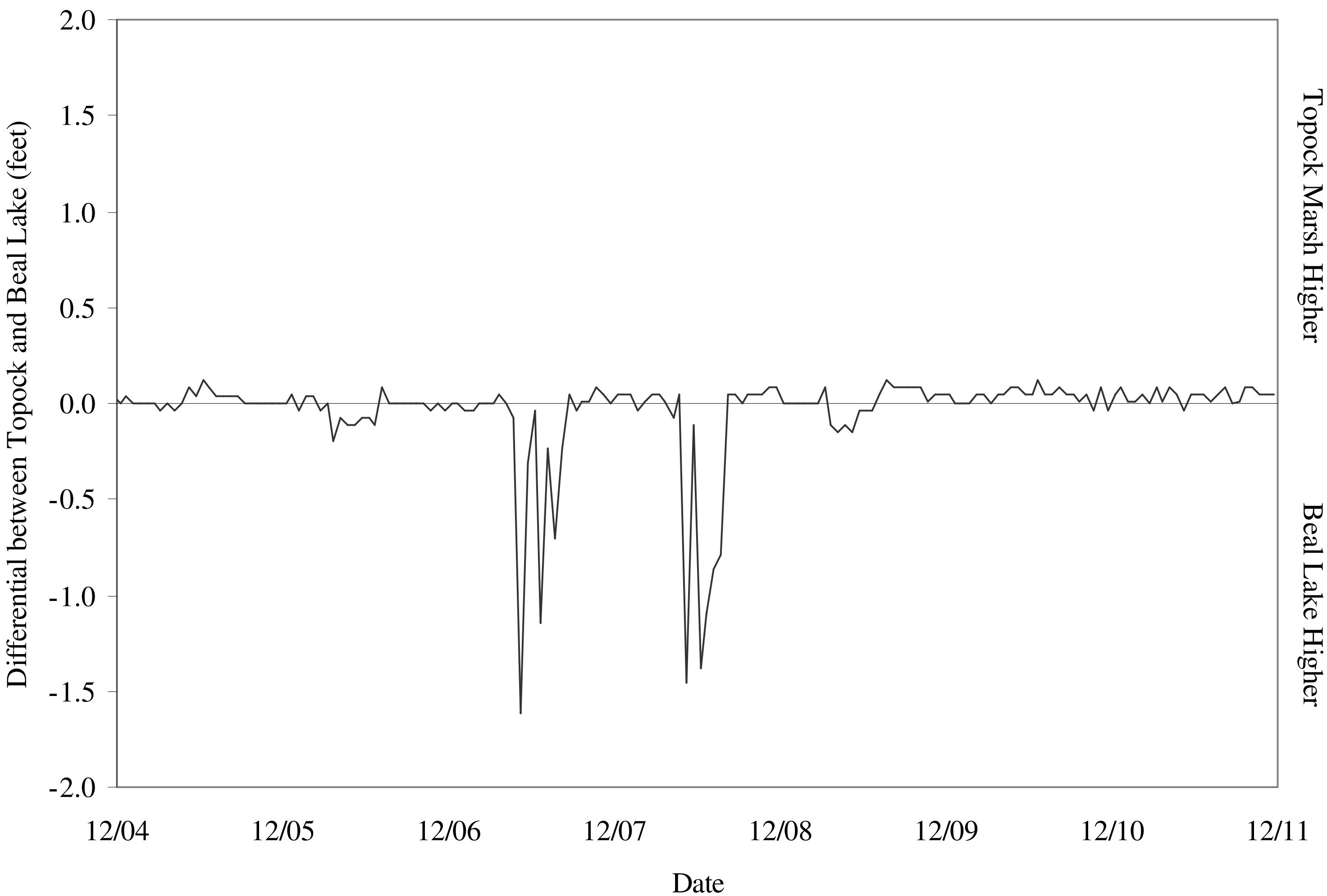
Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 13 November, 2005.



Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 20 November, 2005.



Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 27 November, 2005.



Appendix B – Continued. Water level differential between Topock Marsh and Beal Lake for the week of 4 December, 2005.